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Advanced Concepts for Avionics/Weapon System Design, Development and Integration

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

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ADVANCED CONCEPTS FOR AVIONICS/WEAPON SYSTEM DESIGN, DEVELOPMENT AND INTEGRATION

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THEME AND OBJECTIVE

In order to realize the required performance in the development of modern military aircraft, full advantage is taken of the rapid advances in the computer and electronic technologies. Thus, as each new aircraft design depends increasingly on avionics, the overall system becomes more versatile, but also more complex.

Modern weapon systems are being structured with more interdependency among subsystems. However, potential maximum benefits of subsystem and weapon system development integration have not yet been realized.

In order to realize the benefits of advanced integration ~~concepts~~ and maintain compatible timescales throughout ~~the~~ subsystems development and test phases, intelligent integrated design concepts and proper coordination of the development program are essential.

New design ~~and~~ development strategies should be considered in order to achieve the technical and performance benefits expected of highly advanced and integrated avionics/weapon systems in an economical and timely manner. The applicable design and development concepts ~~being~~ considered ~~as appropriate~~ for ~~presentation and discussion~~ in this meeting are ~~as follows:~~

- Initiate design in terms of overall system to satisfy operational requirement
- Conduct parallel design and development activities in all relevant disciplines
- Retention of design and application flexibility and growth in subsystems by means of appropriate data processing and subsystem inter/intracommunications structure
- Planning of logistic support elements including reliability, maintainability and supportability as well as life cycle cost considerations
- Comprehensive integrated ground testing prior to airborne evaluation of the weapon systems.

The objective of this meeting is to exchange information and ideas among the various disciplines involved in weapon system design to the benefit of integrated system developments for future defense programs. The meeting is also expected to contribute to a mutual understanding of the tasks of all specialists involved in the realization of integrated weapon systems.

THEME ET OBJECTIF

Afin d'obtenir les performances requises au cours du développement des avions militaires modernes, on exploite pleinement les progrès rapides qui caractérisent les technologies des ordinateurs et des équipements électroniques. Ainsi, puisque la conception de chaque avion nouveau dépend de plus en plus de l'électronique aérospatiale, le système, dans son ensemble, gagne en polyvalence mais voit également s'accroître sa compléxité.

Dans la structuration des systèmes d'armes modernes, on vise à une plus grande interdépendance entre les sous-systèmes. Cependant, tous les avantages potentiels que l'on peut tirer de l'intégration, au stade du développement, des sous-systèmes d'armes n'ont pas encore été obtenus.

Pour profiter pleinement des avantages des concepts avancés d'intégration et conserver des échelles de temps compatibles tout au long des phases d'essai et de développement des sous-systèmes, il est essentiel d'avoir des concepts d'intégration intelligents, au stade de l'etude, et une bonne coordination du programme de développement.

Il importe de prendre en compte les nouvelles stratégies de conception et de développement pour retirer les bénéfices attendus, au plan de la technique et des performances, des systèmes d'armes et des équipements électroniques de bord hautement avancés et intégrés, de façon à la fois économique et opportune. Les concepts applicables, au plan des études et du développement, qui sont considérés comme propres à donner lieu, au cours de cette réunion, à la présentation de communications et à des débats, sont les suivants:

- Entreprendre la phase de conception en tenant compte du système dans sa totalité afin de satisfaire aux impératifs opérationnels
- Mener parallèlement des activités d'étude et de développement dans toutes les disciplines impliquées
- Maintenir la souplesse de conception et d'application au niveau des sous-systèmes grâce à un traitement de données approprié et à une structure de communications à l'intérieur des sous-systèmes et entre ceux-ci
- Etablir les éléments de soutien logistique, y compris la fiabilité, la facilité de maintenance et d'appui, ainsi que les considérations relatives au coût total du cycle de vie
- Procéder à des essais au sol complets sous une forme intégrée avant de passer à l'évaluation des systèmes d'armes dans les conditions de vol.

Le but de cette réunion est de faire naître des échanges d'informations et d'idées entre les diverses disciplines impliquées dans la conception des systèmes d'armes, pour promouvoir le développement des systèmes intégrés dans le cadre des futurs programmes de défense. Cette réunion devrait donc contribuer à accéder à une compréhension mutuelle des tâches incombant à tous les spécialistes impliqués dans la réalisation des systèmes d'armes intégrés.

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TECHNICAL EVALUATION REPORT

by

Walter H.Vogl and Jesse C.Ryles

1. INTRODUCTION

The 45th Avionics Panel Symposium on "Advanced Concepts for Avionics/Weapon System Design, Development and Integration" was held at the Lester B.Pearson Building, Ottawa, Canada, from 18 to 22 April 1983. The meeting was a multi-panel symposium with participation of the Flight Mechanics Panel (FMP), the Fluid Dynamics Panel (FDP), and the Guidance and Control Panel (GCP) of AGARD. The compilation of papers is published as an AGARD Conference Proceedings.

2 SYMPOSIUM THEME

The theme addressed the design and development approaches to achieve the inherent advantages of highly integrated system structures. The increasing interdependency among the avionics subsystems of modern airborne weapon systems and the opportunity to share information among these subsystems was an important area to discuss at this time. Advances in system architectures, software development, information transmission concepts, displays, simulation approaches, etc., were perceived to be important areas to address in this symposium to lead to more interdisciplinary system design approaches for future mission and cost effective aircraft avionics designs.

3. PURPOSE AND SCOPE

The purpose of this symposium was to provide a common understanding of all disciplines involved in the airborne avionics system design. The participation of the whole range of interests from customers, services, institutes, and industry and the timely discussion which followed indicates the Program Committee's aim has been realized. Discussions were held after each paper and critical issues opened up some controversial areas. Although time was not sufficient to deal with all these controversial areas in detail, there was considerable discussion after the meetings and during the breaks by the various authors and observers which were found to be very beneficial. This evaluation will discuss the concern from the viewpoints of use, operational issues and requirements, state-of-the-art, assessment of technology, identification of pacing technology, and critical needs for research and development, major challenges and trends; and finally, provide an assessment of the material presented and formulate recommendations for future action.

4. SYMPOSIUM PROGRAM

The program of this symposium was arranged in four specific sessions with a Panel Business Meeting at the end.

Session I, System Design Criteria, addressed the overall issues of weapon system, air vehicle, and avionic system requirements.

Session II, Avionics and Systems State-of-the-Art, dealt with the subject of avionic systems integration, fault tolerant design approaches, fault detection and bus structured systems architectures.

Session III, System Development Concept, considered modeling and operational analysis, hardware and software system design concepts and hardware/software interface approaches/issues.

Session IV, System Integration and System Test, addressed staged avionic system integration in ground-based and airborne environment, including simulation/stimulation and test facilities, as well as final system airborne performance demonstrated.

5. TECHNICAL EVALUATION

When the subject was selected for this symposium, it was clear that it would not be possible to cover each aspect of integrated engineering to its full depth. Rather, it was the view to provide a forum for exchange of the various ideas and identification of proven methods of how to proceed for a technically and economically efficient materialization of complex avionic systems forming an essential part of the overall weapon system. After the four days of discussion, it was noted with satisfaction that the goal of the conference had been fully met.

The Keynote Address, delivered by Vice Admiral Seymour, US Navy, addressed the fact that several basic aspects have to be taken into account in the modern engineering business, particularly in the attempt to balance between the technical feasibility and finanacial affordability. He addressed several ways as potential solutions for consideration: introduction for new cost oriented standards; new avionics systems architecture to enable fusion; need of reconfigurability for easy updating of both hardware and software; and for the upgrading of the whole system after several years of operation. In summary, the Admiral identified a threefold challenge for the engineer's design work; a system must be operationally available, maintainable and affordable. This address was very well received by the participants and is included in the Conference Proceedings.

Session I covered overall weapon system, air vehicle, and avionic system requirements. The first paper highlighted technology advancements in electronics, computers and software which had yielded significant improvements in avionic subsystems. The second paper identified operational requirements which drive weapon control system design. The third paper emphasized the necessity of implementing operational readiness guidelines in; design for testability, operational fault tolerance, diagnostics and self-healing, post flight extraction/analysis and integrated test and maintenance. The fourth paper presented a computational approach available and utilized by NWC, China Lake, CA to evaluate the relative force level effectiveness of different technologies. The fifth paper stressed the need for a new approach to system design in the future to avoid aircraft from entering the inventory with out-of-date electronics technology. The seventh paper reviewed overall structuring criteria and concepts as well as the sensor/subsystem/software issues related to the problem. The eighth paper addressed the fact that the electric/electronic equipment of modern aircraft is, or will be, exposed to greater electromagnetic stress due to the use of fiber composite materials, increasing susceptibility of modern electronic components, and increasing dependence of modern aircraft on proper functioning of electronic equipment. The ninth paper discussed the six interfaces, i.e., operating/machine interface, software interface, and four busses (internal, external, avionics bay and video), defined as necessary to ensure optimum development of a crew station for multi platform applications of the 1990's weapon systems. The tenth paper dealt with an integrated head-up (HUD) and head-down (HDD) display concept employing new optical technologies which promise improved interaction between the pilot and weapon system. The eleventh paper attempts to stimulate new views and approaches to the problem of proper functional integration of the man and avionics technical means. The twelfth paper describes the elements of a US Navy Advanced Aircraft Armament System Program which to date have been pursued in only a limited degree due to a lack of funds. The last paper presented the results of a study to achieve maximum standardization between the aircraft and external stores while minimizing: (1) the modification studies required for each type aircraft/store type; (2) the development of new equipment specification for each store/aircraft type; (3) the installation and wiring charges required for each new store application in an aircraft.

Session II dealt primarily with the subject of Avionic Systems integration, fault-tolerant design approaches, fault detection and bus structured systems architectures. The first paper presented the Fighter/Attack aircraft of the future as a highly integrated weapon system, integrating (vice stand alone) function/subsystems such as penetration, target acquisition, weapon delivery, threat detection and suppression and flight engine control. Also discussed were the issues relating to the architecture of such near-future systems wherein sensor blending/data fusion/high speed operation are to be successfully achieved. The second paper described in some detail the current F/A-18 and indicated some of the possible enhancements to be made on the aircraft in the future. The third paper provided a detailed look at the UK MOD Defence Standard (DEF STAN 00-18) which is the definitive UK Standard for digital interfaces in aircraft. The fourth paper was concerned with the subject of Techniques for Interbus Communication in a Multibus Avionic System. The fifth paper noted that with the advent of MIL-STD-1760 (Standard Stores Interface), while system transparency is preserved with minimal restrictions imposed on the airframe manufacturer, it would still be very difficult to meet the standard, physically and electrically, with discrete wiring. The sixth paper dealt with the issue of evaluating network communication techniques to arrive at promising candidate approaches for 1990's advanced avionics architectures. The seventh paper gave a description of a microprocessor control, ground-based test set for the F/A-18 aircraft. The eighth paper dealt with first level integration maintenance and armament systems and described an integrated maintenance approach that produced many advantages. The final paper was concerned with computer graphics techniques for aircraft EMC Analysis and Design and described an effective computer-aided system for prediction of the potential interaction between avionics systems with particular attention paid in the paper to antenna-to-antenna coupling.

Session III covered a broad range of avionic system and subsystem integration issues. The first paper dealt with the experiments on the human factors aspects of the display system for a television guided lock-on missile for use against ground targets, such as will be employed by the Federal Republic of Germany. The work encompassed head-up displays, head-down displays, and helmet mounted displays. The second paper outlined the software development environments over the last twenty years, using as examples aircraft developed by British Aerospace. The problems of rapid growth of computer requirements and activities to address these problems are detailed. The third paper described the Avionic Systems Demonstrator Rig at British Aerospace which represented a complete aircraft system, linked to an advanced cockpit, appropriate to the next generation of tactical combat aircraft. The fourth paper outlined the development of communications and navigation identification (CNI) systems from the original concepts which were just a collection of individual equipments, through to a concept of an integrated CNI discussed in this paper, in which several receiver-transmitters are interfaced with a signal processor. The fifth paper describes a computerized technique to assist in assessing the vulnerability of specific delivery tactics. The sixth paper described and discussed current technology, i.e., beam penetron and shadow mask, raster and stroke writing, and then continued with a review of a five-phase program of assessment and demonstration of advanced technology displays. The seventh paper described an approach based on weighting the individual attributes of the system to assess the value of complex systems. The eighth paper described the research program using the F-16 aircraft to develop and flight-validate advanced technologies to improve fighter lethality and survivability. The ninth paper covered most of the avionics and weapon management aspects of future aircraft, although the main concentration was on the weapon. The tenth paper discussed preferred software tools for the in-service support phase of Tornado, for support of major avionic retrofits in general and for the support of the description and the development of future aircraft. It was considered that no completely satisfactory tool existed at the time; therefore, to meet this requirement, CADAS was developed. This is a computer aided design tool, designed to make maximum use of commercially available operating systems. The eleventh paper dealt with the need to study EMC problems in weapon systems and emphasized the need to consider the EMC aspects from the very beginning of a project, and plan manning levels, work programs, etc. The final paper described a program initiated in 1975 aimed at providing guidance on how to design avionic systems for the 1980s. Design considerations included cost, reliability and maintainability. The work led to the building of a demonstration system in a Cessna 402 twin-engine general aviation aircraft.

Session IV concentrated on the demands for future engineering work: to develop, provide and apply computer-aided integration, simulation and test methods and facilities with all the hardware in the loop. The first paper addressed two main elements which helped to overcome the inherent engineering problems for integrating such a complex system: close organizational relationship between the designers and the users has to be established from the beginning of the project and the use of highly developed simulation and support devices for dynamic integration on the ground and in the air. The second paper explained the unique capabilities and design of the Dynamic Flight Simulation and Crew Station Evaluation Facility built at the Naval Air Development Center as they pertain to avionics system development and validation and to assess the system design with the man in the loop, in a flight envelope which by far exceeds that of in-flight simulation or flight tests. The third paper reviewed the methods and facilities applied to the avionics and weapon integration of the PANAVIA Tornado aircraft and then advanced ideas on how to evolve these proven concepts to more complex systems. The fourth paper described hardware-in-the-loop simulation techniques used in the development of the Sea Harrier avionic system and the techniques which were adopted to ensure that the hardware and associated software were tested, validated, and integrated into the aircraft. The fifth paper described the Northrop Avionics Simulation package (Executive Support System) which has been designed to support the development of fault tolerant avionic systems and is currently used for the F-5G, F-18L and F-20 avionics models. It provides a mechanism for developing and testing several avionic core configurations as well as avionic simulation and application modules. The sixth paper addressed the methods applied for testing the PANAVIA Tornado Autopilot and Flight Director System (AFDS). A new automated AFDS Cross Software Test System and facility was presented in detail. The seventh paper provided a summary of challenging concepts for practically useful, cost efficient, and automated validation techniques for high integrity software. A promising technique identified as "symbolic execution" is discussed and the results of a detailed study are presented. The final paper discussed the approaches and problems associated with using a static avionics development and test rig. A new dynamic test technique is described, the advantages illuminated and its application to the Tornado Air Defense Version aircraft outlined.

6. CONCLUSIONS

It is extremely difficult for a few people to formulate specific findings of a symposia with such a broad range of technical coverage and attended by specialists from an equally broad range of interests. The principal conclusions from the paper presentations and subsequent questions/discussions are as follows:

6.1 The rapid advancement of electronics and digital processing technology has had and will continue to have a profound effect on avionics system design, development and testing concepts/techniques.

6.2 The emergence of digital information coupling among avionics subsystems has contributed to initial interface standardization such that some degree of technology transparency exists for update and retrofit of avionics subsystems.

6.3 Advancements in avionics architecture and information sharing concepts should lead to enhanced fault tolerance, on-board diagnostics and performance capability as well as reduced logistical support for future avionic systems.

6.4 As avionics subsystems become more integrated and highly interactive, more effective and economical techniques will be required for software design, development and testing.

6.5 Fundamental studies are needed which illuminate the trade-offs among avionics system architecture choices and the significant variables of interest such as:

Weapon system application
Misssion availability
Technology state-of-the-art implemented
Fault tolerance/diagnostic capability
Software design, development and test
Logistic supportability
Life cycle cost

7. RECOMMENDATIONS

7.1 The timely dialogue and interest displayed by the participants at this meeting in avionic system architectures, software development and validation, and system integration and test suggests that future meetings should be of less breadth and more depth of coverage in each of these subjects.

7.2 Specialists meetings devoted to each of these subjects or a two to three day symposia limited to one or two of these areas would be a valuable forum for the Panel to consider for future meetings.

ANNEX

GENERAL COMMENTS

1. SELECTION OF PAPERS

Over 70 abstracts were received in response that called for papers, some of which were received too late for consideration at the meeting of the program committee. The committee had a difficult task in selecting approximately 41 papers which were considered to be the optimal number for a 4-day symposium, and was obliged to reject a large number of the abstracts submitted. The objectives were to provide a selection of high quality papers for each of the sessions that would fit well within the theme of the meeting and give a good impression of the range of interest and quality of work in the countries participating. The distribution of papers per country is shown below:

2	Canada
5	France
7	Germany
1	Italy
8	UK
18	US

Attendance: The total number of participants was 217 including panel members. The National distribution was:

111	Canada
34	USA
22	W. Germany
21	France
17	UK
6	Italy
3	Belgium
1	Denmark
1	Greece
1	Netherlands

2. LOCAL ARRANGEMENTS

The symposium was held in the Lester B.Pearson Building. The facilities were unanimously recognized as the best ever offered for a AVP meeting. Canadian Host Coordinator, Dr MacPherson, is to be congratulated for his support and on the thoroughness and the success of the arrangements. The Canadian National Delegate present at the meeting was Dr D.Schofield. Participants were entertained at an official reception in the Lester B.Pearson Building. A technical tour was also conducted through the Satellite Test and Integration Facility, David Florida Laboratory, Ottawa.

KEYNOTE ADDRESS

by

Vice Admiral E.R.Seymour
Commander
Naval Air Systems Command
Washington, D.C.
USA

It is a pleasure to be here. I appreciate the kind words of the introduction. In the introduction it was noted that I became an aeronautical engineer in 1962. I would like to point out that this was in the area of propulsion, not avionics.

Mr Vögl in his opening remarks used the classic picture of airplanes as perceived by the different speciality fields in the aeronautical world. The propulsion specialist thinks of an airplane as a flying engine while the avionics specialist thinks of an airplane as a flying antenna. That is one of the reasons over the last three years I have found it very useful to get out and talk to avionics groups. I have talked to a number of avionics groups in the United States and this is my first opportunity to speak to avionics groups outside the United States. It is useful to spend time with you just to explain some of the necessities of other parts of the aerodynamic world.

In my presentation I will concentrate on the need to reduce avionics costs. With the multibillion dollar budget that I have this year, the main thrusts that I feel in Washington, the pressures on me, are to reduce costs. This is primarily because we are now spending two digit millions of dollars for an airplane. When I started flying in the 1950s we were buying different aircraft, not as capable, but they cost less than a million dollars each.

If escalated by inflation only, not the extra money spent for improved capability, we would certainly not be up to 40 million dollars per aircraft which is where we are with some of our airplanes today. All the pressure to reduce cost, and that is essentially on unit cost, is driven by the fact that we cannot buy all those systems that we think we need.

We are part of the problem in a way because we insist on improved capability, but I think you will see that to some extent we need to do that. We have done things like insist on multimission capability in aircraft in the United States Navy. The F/A-18 was our first example of one that was designed with that in mind from the beginning. When we first chose the F-17 from the Air Force light weight fighter competition, the first step we took was to totally redesign the aircraft to make it multimission capable. The main reason for that is that we were trying to put that aircraft on aircraft carriers, aircraft carrier real estate is the most expensive in the world. I have heard it quoted at 96 thousand dollars per square inch. Given that that is the amount of real estate we are operating with, clearly you want whatever you put on that real estate to be capable of doing almost anything.

In 1947, the US Navy was very carefully trying to get jets on board carriers. We were inventing our first carrier-capable jet and if you recall those days we gave up 95% of our ground payload to go from propeller to jet aircraft because we felt that the speed performance was necessary. We got to Korea and the Navy did not have any jet aces because in those days of bringing in the new technology we were not able to achieve both speed and maneuverability and still get the aircraft on the carrier in the early 1950s. Well, it is my view that we have achieved the required capability now. The performance capability and maneuverability, and speed of the F-14 and F/A-18 and the current crop of US fighters is sufficient. There are other advances in technology that we are pursuing, of course, like composites, but, in general, in the aerodynamic world it is my view that, for the near term, until the choice is made to make the quantum jump to hypersonic vehicles, we have basically reached what we need in terms of aerodynamic performance.

The improved performance required for our next generation of aircraft depends on the threat, what is available to counter that threat, and the tactics for employing Naval Air Forces or Air Forces. In my view we are going to need major increases in the availability of sensor information. We are going to need to find a way to get sensor information available on board the airplanes, but, even more so, available to the pilot and available to be used. The filtering of that data is what I call fusion; I have information available from a number of sensors and somehow I fuse it so that it can be used by the operator giving him only that information which is necessary to accomplish his job and it filters or integrates the other input information to provide that output information.

The need to provide all this information, though, can be expected to escalate the avionics cost. This cost increase per aircraft in turn set up a vicious circle of management problems which I have alluded to. For example, if the avionics in the weapon system on an aircraft are more expensive by basically a historical thumb rule you can expect the logistics and flyaway cost of the aircraft to be more expensive. The more costly the aircraft, the fewer I buy.

As you all know, when we operate aircraft it is a dangerous business to some extent and we have attrition. In the United States we do not buy a stockpile of aircraft and then use them gradually until we get down to the minimum force level and then buy another stockpile. We buy only the aircraft needed to maintain the minimum fleet level for the current year. The media reports that the attrition aircraft, the aircraft purchased to replace those lost, cost nearly twice the original cost and this is essentially true. The limited quantities that we are able to buy because of increased costs then lead us to a numerical disadvantage vis a vis the enemy and place major pressures on the management or the fleet commander and the support systems that are supporting the fixed force levels of aircraft. Once we reach that state, we in Washington say we can reduce that pressure if we increase the performance of the next system coming around the corner. In other words – "get more bang for the buck" – get more performance out of what we do buy. These increased performance requirements start the whole cycle all over again. This cycle is the basic United States Department of Defense Research and Development problem.

Twenty years ago one third of our aircraft costs was avionics. Today, avionics are two thirds the aircraft cost. Twenty years from now we cannot have all the aircraft costs in avionics. I have talked about the cost of avionics systems having gone up as though it were bad in itself and I do not want to leave that impression. There are a number of people in Washington talking to me that way, but in all honesty, even though the costs have gone up significantly, the capabilities have gone up tremendously. In World War II we probably had no more than 50 pilots that regularly flew at night off carriers and that was towards the end of the war. In the early 50s we had a number of operational days when we did not fly because the weather was too bad. Today, normally, if there is an operational need, carriers will launch in any weather. The aircraft can return in zero-zero weather conditions if everything is working properly. The A-4C that I started flying in 1965 in Vietnam had a simple navigation system and no bombing system at all. The A-4Es that I flew the next year had probably the first generation of a computer aided bombing system and it was tremendously helpful to those of us dropping bombs at the time. I was the project manager when the A-7 was introduced in 1970. The A-7E was basically our first light attack catapult aircraft with a computer driven and operated fully integrated weapon system. With a weapon system like the A-7 we can send a pilot out and on the first pass on a strange target, he can roll in and get the bomb within 50 feet of the target. That is fairly impressive having flown the A-4C early in my career. With the A-4C, if you knew where the targets were, were accustomed to the pattern, and were able to keep the airspeed under control, you could probably get the bomb 150 feet from the target.

Though coupled with improved performance, avionics has been the significant factor in the growth of military aircraft costs. There are very few times in the government life cycle when it can afford to pay to get a certain performance no matter what the cost. Typically, wars tend to be one of these times. Peace is not one of these times; it should not necessarily be one. I am not suggesting that it should be. One of the major points I would like to make at this AGARD Avionics Panel Symposium is that you should not be primarily interested in more performance from avionics independent of costs. Costs have to be one of your drivers. It is one of the government's drivers and it is probably one of your commercial customer's drivers although perhaps not as large. But in the case of the government where we are using taxpayers money to buy a requirement, it is incumbent upon us – and pragmatic politics demands it – that we trade off performance for reduced costs. The improved performance needed for the next generation of aircraft must be achieved with an affordable cost objective or it will be self defeating. The improved performance will be a nice thing but no one could afford it. I have been emphasizing the need to reduce procurement costs of avionics, but the reduction of the life cycle costs for maintenance, depot overhauls, and systems spares should also be understood as included in the need to develop affordable avionics systems. Given that the cost of avionics is a problem, what can we do about it?

This symposium is useful because you are going to look at new avionics concepts and solutions. We have thought in the past of ways to solve this problem, we have made efforts right along to reduce costs. Where should we go from here? Should we go to more Very Large Scale Integrated Circuits (VLSIC)? As you know, we have an R&D program in the United States for Very High Speed Integrated Circuits (VHSIC) and a number of us think this is very attractive. I can see some great benefits to it. This is a near term solution that is already in research and development. Generally speaking, the cost of avionics historically can be measured as a function of its weight. Increase the number of black boxes, the costs of avionics goes up; increase the density of avionics and the costs go up. VLSIC and VHSIC both promise some major advances along with digital optics and fiber optics, i.e., if we really let them, they can drive down the size of avionics. History will tell you that if we have 20 cubic inches available on an airplane someone will find a way to fill it up and will probably fill it up with more dense equipment; this means costs will go up. Well, while I think these things are useful in the near term, what I really would challenge you with is a far term concept. It could still be done in five years, but what needs to be done is to start thinking about it now because a lot of people would say that if we make it lighter we will have more space and we will add some more sensors. How about standards? Well, the Navy has been leading the government in attempting standards. The thought is that if we had standards we will probably get production cost efficiencies in the economies of scale. One could raise the question do we really save money, do we really gain, or do we block innovation? I would have to vote that we block innovation. Standards are beneficial during production. The trend that shows avionics costs increasing indicates that standards do not seem to be the only answer.

Digital multiplexing buses (MUX buses) are now in a number of airplanes and being retrofitted into other airplanes. This provides better communication between black boxes and better capability to upgrade boxes over the near term, but it still leaves the black boxes. The challenge might be an entirely new avionics systems architecture. I will be the first to tell you that I do not know how to do this. But it really is something that is necessary in research and development and would be a good place for research and development to look at. What it might do would be to provide a quantum jump towards the state-of-the-art in advanced integrated avionics systems. As I mentioned before, a new avionics systems architecture needs to provide the fusion. Somehow, the military side of development needs to start rethinking logistics if you could get a total radar on a single IC board. We do not have this yet, but we have to start rethinking because we cannot go out and buy spares after the system has already been built. Avionics systems will be more software intensive. We must be more adept or more knowledgeable in updating or correcting software. An example I use is the F/A-18 Flight Test Program to modify the software we needed for the flight control laws. We planned to do this in one month. The first two times we did it took us six months each at least. This should have been no surprise, but we did not plan it that way. A challenge for the future is that you must demonstrate to those reviewing your work that you have, in fact, considered cost or the economic realities as a part of your total design. These kinds of questions are traditionally asked annually when I go to congress to defend the budget. This is going to be a dichotomy now. I am going to tell you that we need to do evolutionary vice revolutionary changes. Evolutionary aircraft is the way to update airplanes. What I have thrown into your laps this morning is the challenge that a revolutionary invention such as new avionics architecture is very hard to sell because it is revolutionary. It will take a lot of testing and product proving to show that it really was a good invention.

In conclusion, regardless of the degree of technological advancements the future of avionic design and architecture may bring, the system must be operationally available and maintainable in the field and, as I have emphasized for the last thirty minutes it must be affordable.

SUMMARY OF SESSION I
SYSTEM DESIGN CRITERIA

by

J.C.Ryles
Session Chairman

This Session was organized to address the overall issues of Weapon System Requirements, Air Vehicle Requirements and Avionic System Requirements.

Paper number one entitled "System Architecture: Key to Future Avionics Capabilities", by Mr G.R.England, Director, Avionic Systems Department, General Dynamics Corporation was arranged to be a keynote or theme setting presentation for this session. Mr England highlighted technology advancements in electronics, computers and software which had yielded significant improvements in avionic subsystems. He pointed out how independent advances in technology has not yielded the system functionality required and resulted in complex developments with higher spares and life cycle costs. He presented a challenge for the future to depart from past and current system design practices. He advanced the proposal to work in concert the areas of physical, functional, information exchange and system control architectures while employing standard, self-testing modules to arrive at performance and low life cycle cost objectives for future systems.

The second paper was entitled "Tactical Requirements Impact on Integrated Avionics/Weapon System Design", by Messrs J.F.Patton and T.Spink of Westinghouse Electric Corporation. Mr Spink presented the paper, identifying operational requirements which drive weapon control system design. He emphasized the air-to-ground weapon delivery, battlefield interdiction mission outlining the design requirements for an integrated attack system. Conclusions were advanced regarding the best technology path for pursuit to yield a weapon control system that assures a high probability of multiple target kills per pass and maximum survivability.

The third paper was entitled "Operational Readiness and Its Impact on the Avionic System Design", by Messrs J.F.Irwin and K.A.Short of the Northrop Corporation. Mr Irwin's presentation emphasized the necessity of implementing operational readiness guidelines in design for testability, operational fault tolerance, diagnostics and self-healing, post flight extraction/analysis and integrated test and maintenance. A managerial and technical roadmap for incorporating operational readiness goals in the next generation fighter was reviewed.

Paper number four by Mr R.T.Haven and Dr M.Cartwright of the US Naval Weapons Center was entitled "Avionics Concept Evaluation at the Force Level". Dr Cartwright presented the computational approach available and utilized by NWC, China Lake, CA to evaluate the relative force level effectiveness of different technologies. The methodology for augmenting the data base utilized with relevant technology attributes important to future designs was discussed.

The fifth paper was entitled "A Future System Design Technique Based on Functional Decomposition, Supported by Quantifiable Design Aims and Guidelines for Minimum Maintenance Costs" by Mr D.Oldfield and Dr L.Salmon of the UK Royal Aircraft Establishment. This presentation stressed the need for a new approach to system design in the future to avoid aircraft entering the inventory with out-of-date electronics technology. Functional design was proposed as an approach to avoid the concentration on hardware solutions too early in the development cycle. Methods of producing functional designs were illuminated and experience to date with the approach summarized.

Paper number six was withdrawn from the program with insufficient time to make an appropriate substitution.

Paper number seven was entitled "A Modular System Structure for the Requirements of the Application", by Mr P.Catel of Electronique Serge Dassault. This Paper reviews overall system structuring criteria and concepts as well as the sensor/subsystem/software issues related to the problem. System structuring approaches developed up to the early 1980 time frame with the contemporary computer memory limits are outlined. A new system structuring approach is discussed which simultaneously adapts the computer characteristics with the method of realization of the system structure.

The eighth paper by Mr D.Jaeger of Messerschmitt-Bölkow Blohm GmbH was entitled "Increasing Significance of Electromagnetic Effects". The presentation indicates that the electric/electronic equipment of modern aircraft are or will be exposed to greater electromagnetic stress due to the use of fiber composite materials, increasing susceptibility of modern electronic components, and increasing dependence of modern aircraft on proper functioning of electronic equipment. Existing specifications are cited as not adequate and suggested solutions offered.

The ninth paper was entitled "Avionics/Crew Station Integration", by Mr W.G.Mulley of the US Naval Air Development Center. The six interfaces defined as necessary to ensure optimum development of a crew station for multi-platform applications of 1990's weapon systems were discussed. These interfaces included operator/machine interface, software interface and four busses (internal, external, avionics bay and video). A discussion is also provided of the relevant issues in the areas of weapon system, system development, production, operational and support costs.

Paper number ten by Madame B.Simon of Avions Marcel Dassault was entitled "A Concept for Integration of Head Up and Head Down Displays". This paper dealt with an integrated head-up (HUD) and head-down (HDD) display concept employing new optical technologies which promise improved interaction between the pilot and the weapon system. The paper advances several benefits from this concept. First, it will considerably ease the pilot transition between HUD and HDD. Secondly, the concept of a "transparent instrument panel" will enable very low level flight paths and permit high angle approaches to be accomplished. General benefits include increased field-of-view and larger quantity of displayed information.

The eleventh paper was entitled "Guidelines and Criteria for the Functional Integration of Avionic Systems with Crew Members in Command", by Mr F.W.Broecker of the Federal Agency for Military Technology and Procurement, W.Germany. This paper attempts to stimulate new views and approaches to the problem of proper functional integration of the man and avionics technical means. It outlines the operational and work environment for the crew, discusses several system approaches and describes guidelines and criteria used therein. A draft of Guidelines and Criteria is proposed for discussion within AGARD and the technical community in general.

Paper number twelve was entitled "Navy's Advanced Aircraft Armament System Program Concept Objectives", by Messrs T.M.Leese and J.F.Haney of the US Naval Weapons Center. This paper describes the elements of a US Navy Advanced Aircraft Armament System Program which to date have been pursued in only a limited degree due to a lack of funding. Deficiencies in past armament systems are discussed and related to the requirements of future systems. This discussion unfolds into a description of the approach which was planned to be pursued. Design guidelines including rational standards are suggested to lower cost growth, promote interoperability and meet support objectives. An Advanced Stores Management System Laboratory under development is described. The current program is stated to be directed towards the Joint Navy/Air Force development of MIL-STD-1760 (Aircraft Electrical Interconnection System).

The last paper in Session I was entitled "Aircraft and External Stores Interface", by Messrs C.Connan and M.Salaün of Avions Marcel Dassault. This paper presented the results of a study to achieve the maximum standardization between the aircraft and external stores while minimizing (1) the modification studies required for each type aircraft/store type; (2) the development of new equipment specifications for each store/aircraft type; and (3) the installation and wiring changes required for each new store application to an aircraft. The issues related to the evolution and interface of various store types is discussed. Requirements are reviewed and certain tradeoffs briefly given. A proposed architecture is presented and compared to STANAG 3837.

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SYSTEM ARCHITECTURE: KEY TO FUTURE AVIONICS CAPABILITIES

BY
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SUMMARY

Since World War II, the capability of avionics has improved dramatically -- but the ways in which we design and support avionics have changed very little. Similarly, the crew interface with the system is largely unchanged. Modern aircraft still rely, as old World War II aircraft, upon the pilot or crew for integration of information from diverse discrete subsystems, sensors and weapons. During this long period of technology time, each generation of systems has generally (1) become more complex and (2) increased the quantity and rate of information to the crew. In many weapon system implementations, these two factors have resulted in increased problems in the areas of system availability, affordability, supportability and operability. Although the F-16 has broken this trend it is still evident that new system architectures will be needed as mission requirements in the future create added system demands. Traditional avionic design, support and operability approaches will be unable to cope. The size reductions and performance improvements resulting from large scale and high speed integrated circuits will make it possible to re-structure the way avionics systems are designed. For example, standard modules for multi-use applications will be possible. These modules can become the building blocks for a new type of system architecture. Advanced data switching communication techniques will provide the necessary data transfer rates to support sensor fusion, cockpit automation, and fault tolerant processing. Generic signal processors will make shared functions realizable. On-line self-tests consisting of on-chip and special self-test chips will make 100% tests at the airplane level possible. This in turn will allow direct module replacement at the airplane level and will largely eliminate the need for extensive support facilities, allowing aircraft to remain available for the completion of missions.

BACKGROUND AND FUTURE PERSPECTIVE

Modern military aircraft will require significant increases in performance, availability and supportability to meet the increased threat in an affordable fashion. Advances in computer, software and electronic technologies have been and are being made to achieve these increases. Avionic developments during the past 40 years have been characterized by significant advancements in electronic devices -- from analog elements to transistors, to integrated circuits and now into VLSI. Similarly, improvements in software function have been made in individual subsystems. However, while devices and software have shown significant individual improvement, the system level design and support of avionics has changed very little (reference Figure 1). Avionic systems are still characterized by distributed functions with each function or limited groups of functions contained within discrete individual boxes with the pilot as the system integrator. This system concept, which has persisted independent of advancements in technology, has resulted in complex developments, high spares costs, less than optimum functionality and high life cycle costs.

Tomorrow's missions will require sensor fusion, cockpit automation and coupled systems. Subsystems, working together, will provide enhanced capability and increased tolerance to individual subsystem failure.

The role of the pilot will need to change in future aircraft from that of a system operator and integrator, to that of a system manager. The pilot should be able to express goals and intent of operation while the system should integrate the various subsystems and sources of data to accomplish that intent. Only in this manner will the weapon system be able to remain coordinated and effective in the face of the increasing functionality and complexity required to meet the increasing threat. The total aircraft system will include the pilot, the avionic sensor and the computational capabilities -- each in its most effective role. Allowing the pilot to act as a system manager will require the system to have adequate artificial intelligence to be able to make routine decisions, and decisions which rely upon large quantities of quantitative data, on its own. Pilot training requirements will change since the need for

DRAMATIC ELECTRONIC ADVANCES IN PAST 40 YEARS

- HOWEVER -

STILL DISCRETE SUBSYSTEMS WITH DISCRETE INDIVIDUAL BOXES

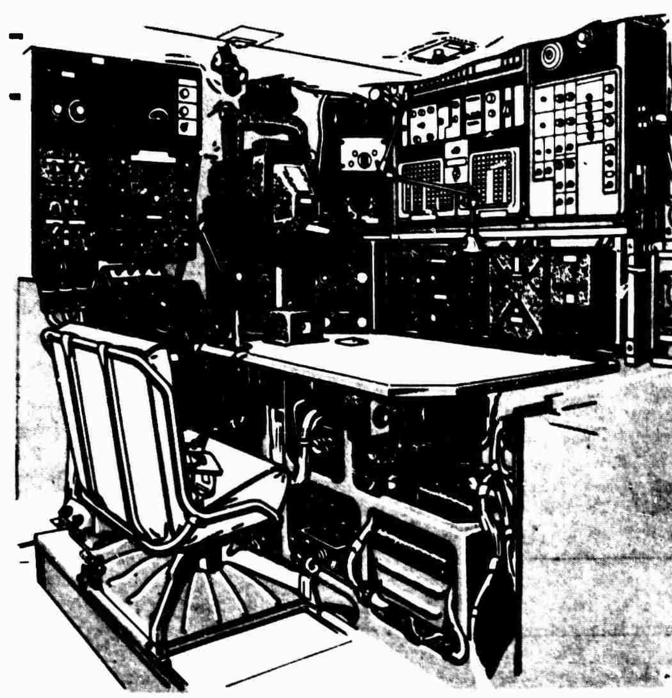

FIGURE 1. DESIGN AND SUPPORT OF AVIONICS HAS CHANGED VERY LITTLE SINCE WORLD WAR II

the pilot to remember large quantities of technical operation details will be replaced by training in military strategy and combined avionic system operation. This new training regimen will, incidentally, be much more transparent to aircraft type and detailed subsystem configuration allowing much more rapid development of pilot proficiency in new aircraft types.

Future sensor implementations will need to be complementary. Improvements in individual sensor raw data will not be adequate to provide the desired levels of detection ranges, accuracy, resolution, etc. Rather, it will be necessary to integrate the data from many discrete sensors to obtain maximum benefit from their individual characteristics. Without such integration, or fusion, of available data the best system answers would not be obtained and the pilot would not be able to manage the increasingly complex system.

The key to achieving these future avionic capabilities is the system architecture. If conventional system design concepts are followed, the desired added capabilities will increase system complexity and will continue a long term adverse downward trend in supportability and affordability. The challenge will be to incorporate these improved capabilities while at the same time improving supportability and availability and while reducing costs.

ADVANCED SYSTEM ARCHITECTURE

The desired future system capabilities can be achieved with current and emerging hardware technology and with an extension of currently developing software and system design approaches. Several key advances that make this possible are:

1) Low-Cost, Single-Chip Digital Processors
2) High-Speed, Single-Chip Digital Multiplex Terminals
3) Single-Chip High Density and High Speed Technology
   - Computer Memories
   - Standard Interface Test Chips
   - Standard Functions
4) Artificial Intelligence Software
5) Intent Driven Design Approaches

For the hardware elements, a key to these capabilities is size reduction. As size shrinks, bringing reductions in cooling and less requirements for power, it becomes evident that the opportunities for implementation of common hardware can become a reality. For example, the size of a MIL-STD-1553 digital multiplex terminal has shrunk from three 5" x 7" electronic cards in 1976 to a single 5" x 7" card today and will shrink to a single 4" x 5" card by 1984. The next step will reduce the size of such a terminal to a pair of integrated circuit chips. Given a standard module package and standard casings and fittings, all avionic equipment could then utilize the same multiplex terminal hardware.

In the software area a similar revolution is occuring. Relatively inexpensive and powerful hardware is allowing the development of computers with 'reasoning' capabilities, able to evaluate alternatives and make value judgements. The ability to do this is allowing new perceptions of the relative roles of the computational system and the pilot in modern aircraft. Artificial intelligence approaches have already been successfully applied in other fields - what remains is the application of those approaches to avionics. Improved hardware and software can be combined to achieve the architectural improvements which are necessary to achieve future goals. Several architectural areas must, however, be treated in concert to achieve the decisive improvements required. These aress are:

- The Physical Architecture
- The Functional Architecture
- The Informstion Exchange Architecture
- The System Control Architecture

THE PHYSICAL ARCHITECTURE

Future avionic systems should be composed of standard, self-testing modules located in integrsted avionic system racks. Analysis of vsrious types of svionic systems hss shown thsr identicsl types of functions sre performed in many diffferent systems and in different parts of the same systems. Figure 2 shows how this commonality of functions is shsred between a group of five aircraft systems. An unusual combinstion of systems has been selected to dramatize the commonality of functions even among diverse systems. If the more conventionsl avionic systems are added to the list, the same sharing of function types is also observed.

AVIONIC SUBSYSTEMS \ COMMON FUNCTIONS	Computing	Analog/Digital Interface	Digital/Analog Interface	Digital/Analog Control	Discrete Interface	Frequency-Digital Interface	Mass Memory	Power Supply	Serial Digital Multiplex
FLIGHT CONTROL	✔	✔	–	✔	–	–	✔	✔	✔
ENGINE CONTROL	✔	✔	✔	✔	✔	✔	✔	✔	✔
ENVIRONMENTAL CONTROL	✔	✔	✔	✔	✔	–	✔	✔	✔
AIR INLET CONTROL	✔	✔	–	✔	–	–	–	✔	✔
AIR DATA & MOTION SENSORS	✔	✔	–	–	–	–	–	✔	✔

FIGURE 2. COMMON FUNCTION TYPES ARE SHARED BY DIFFERENT SYSTEMS

In today's avionic designs, each of these common functions is performed by a unique hsrdware design. Typically, different vendors will provide different hardware even though the functions are identical. This situation exists becsuse current designs emphssize Line Replaceable Units (circa World War II) rather than functions. On the other hsnd, if stsndard interfaces and packaging are adopted (as is possible with a unified totsl architecture), it becomes practicsl to design common functional modules for multi-use applications. These modules, plus unique sensor snd effector interface modules, then become the building blocks for a new type of system architecture. Virtuslly any type of system function can be built from these modules together with suitable software. Because the common module types will be used in many different applications it will be cost-effective to develop special integrated circuit chips and to implement unique production methods to permit such modules to be manufactured in large quantities at low cost.

Figure 3 contains a general description of one such module and lists some of the more important features. Such a computer module is currently feasible using the MIL-STD-1750A processor chip set being developed by the F-16 program. Other modules of the family would be of similar construction. Modules of the type shown in Figure 3 will be physically protected from the flight-line environment to which they will be exposed. The modules will become the Line Replaceable Units (LRUs) and therefore must be designed accordingly. Current module or card design approaches will not suffice.

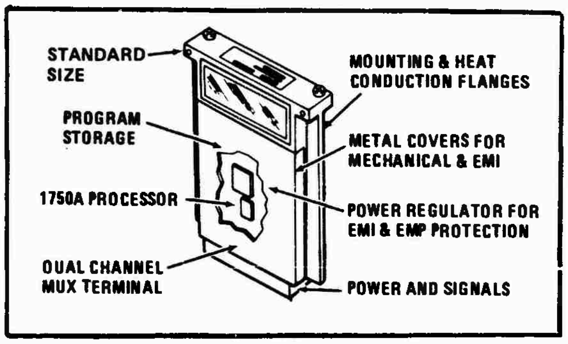

FIGURE 3. TYPICAL COMMON COMPUTER MODULE

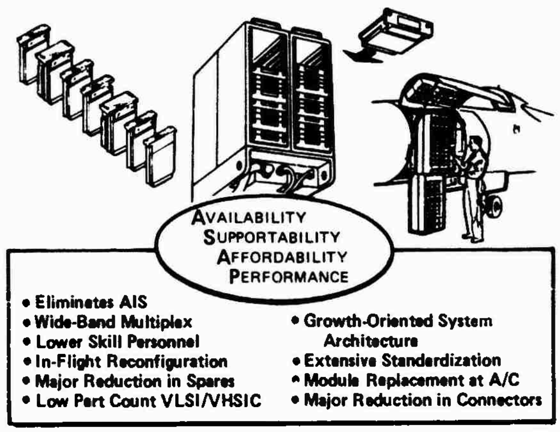

FIGURE 4. ACROSS-THE-BOARD BENEFITS

Direct module replacement at the aircraft level will be a major logistic benefit of the new physical architecture. To achieve this goal, an integrated rack packaging will be used in place of existing LRUs. Racks similar to that shown in Figure 4 will permit ready access to individual modules. Many of these common integrated racks will be used throughout the airplane and can be larger or smaller depending on application. The rack sections will be separately removable from the aircraft to permit back-plane repairs or modifications. Compared to current avionics, these repairs should be very infrequent, since the racks will reduce the stress on connectors and will greatly minimize interconnections when full multiplex communication is implemented between modules. Individual modules will be enclosed in sealed metal cases to provide complete mechanical and EMI/EMP protection. These rugged, sealed modules will permit flight-line replacement. All modules will be cooled by conduction to cold plates in the integrated racks. Either forced air or liquid cooled versions of the rack could be used.

THE FUNCTIONAL ARCHITECTURE

Future aircraft will need to have a functional rather than a subsystem oriented architecture. Emphasis in system operation and design will be on the functions which must be performed to achieve the mission. The physical pieces of sensor/effector hardware required to accomplish the functions will no longer drive system design and implementation considerations. System functions will frequently be accomplished with input or participation from what are now typically stand alone subsystems. Sensing and computation will be performed where it provides the most benefit, rather than where it has been traditionally performed. As a result, in the accomplishment of functions, sensors will augment each other. Detection of targets for example, can be performed by a combination of radar input, EW input, FLIR input, laser input and pilot input to a common functional algorithm. Individual sources of data will be weighed most heavily when the conditions for operation of that subsystem are best. Failure of a sensor will not change the operation of the function, but will merely modify the accuracy, certainty, range, etc., with which targets can be detected to the extent that the failed sensor would have provided data. Pilot workload will be dramatically reduced because formerly separate data will be already integrated and appropriately weighed according to its value. Fusion of the data in this manner will allow the pilot more time to focus upon the intent of his mission and the expression of that intent to the avionic system to allow it to properly weigh decision inputs. A functional rather than subsystem orientation will also provide benefits in the area of system availability. When coupled with the standard modules of the physical architecture, failed devices will be able to be replaced on-line with spare modules to maintain the operation of critical functions. Functional orientation will promote common algorithmic approaches which can be supported by common hardware modules. In addition, it will decrease the tendency to build-in geographical proximity as a subsystem design requirement. Failure of one of these modules will be circumvented by the reloading of a similar module in another part of the system with the appropriate software to continue operation. This reallocation of processing to accomplish functions can range from simple computational modules to complex common signal processing elements. Safety of flight critical systems will also be benefited by a functional approach to system design. Improved system error checking capability can be achieved through the analytical comparison of other aircraft sensor data without the necessity for unneeded duplication of flight critical sensor systems. Reliance will be upon total system capability.

THE INFORMATION TRANSFER ARCHITECTURE

A new type of modular architecture will be necessary to utilize standard modules of the types discussed to accomplish the proposed functional architecture. Multiplex communication will be used between modules, rather than just between LRUs as in existing designs. This approach will largely eliminate many thousands of mechanical electrical connections that are used in current avionic equipment. It is ironic that, while these connectors in current systems facilitate rapid field replacement of defective elements, they also contribute failures that increase the number of maintenance actions. In modern digital equipment, even a momentary break in a connection tends to register as a hard failure. Evidence indicates that connection related problems may be responsible for a large segment of the could-not-duplicate (CND) and re-test-OK (RTOK) problems that tax maintenance resources and that tend to repeat in flight and thereby reduce combat effectiveness.

Figure 5 is a block diagram showing an example and benefits of such an architecture. This example is an inertial navigator that uses digital multiplex to the module level and is built almost totally from standard modules. Elements such as those shown in Figure 5 become building blocks in a conventional sense for larger subsystems and systems in much the same way that the standard modules are building blocks for this element. The same standard, digital multiplex communications interface is used at all levels to simplify design and permit necessary data interchange at all levels of the system.

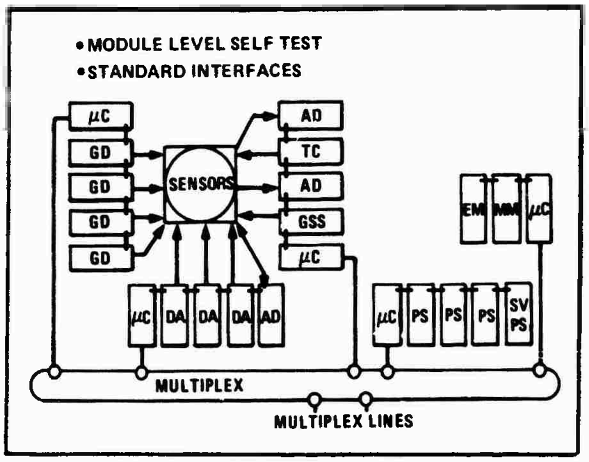

FIGURE 5. ALL-MULTIPLEXED ARCHITECTURE FOR AN INERTIAL NAVIGATOR USING STANDARD MODULES

The two most essential features of the information transfer architecture are the previously described 'multiplex to the module' feature and the reliance upon a switched communication network rather than a bus structure for that information transfer. Dynamically switched point-to-point communications is provided between devices in the avionic system allowing any device to communicate with any other device. This switched approach permits many simultaneous communications to occur, provides alternate communication paths for reliability and reconfiguration, and provides isolation of failures in communications to a single computational module. All of this is accomplished with a highly regular network requiring only one multiplex terminal per computer. Failure isolation is particularly important to flight critical functions which need to interact with the remainder of the avionic system but which must be protected from failure in non-flight-critical and non-redundant subsystems. The switched network information transfer architecture is also fully extendable to provide for the transfer of non-digital information such as video, electrical power and RF energy. In a fully functional architecture the distribution of these types of information must be fully coordinated with the exchange of digital information. The common control mechanism for data exchange provided by the switched network approach achieves this coordination capability, provides regularity in system design, and can dramatically reduce the wiring and control complexity of the aircraft while substantially improving operational effectiveness.

Advanced multiplex networks of the type needed for such applications have already been designed and breadboarded for digital and video information exchange. The networks employ the advanced, fault isolating, switching techniques to provide the necessary data transfer rates to handle both high-speed digital and wide-band video type data. The terminals transmit less than one-quarter watt of power and can be constructed entirely with VLSI chip technology.

THE CONTROL SYSTEM ARCHITECTURE

The complex avionic systems of the future will require improved control mechanisms to ensure reliable and effective operation. The switched network information transfer architecture supports distributed control and provides the freedom to implement any desired combination of central control and local autonomy. Some degree of local autonomy will certainly be required for efficient system operation as the number of simultaneous functions to be accomplished increases. Accordingly, the control in future avionic systems will be accomplished at several levels. At the top level will be the expression of the intent of the mission (and of the pilot). Of necessity, all actions of the total system must be consistent with these mission objectives. Implementation at this level will be accomplished by the pilot and a system level artificial intelligence capability.

The next level will be the control of individual functions, each of which may involve several sensors/effectors. As long as the actions taken at this level are consistent with the top level intent of the mission/pilot, autonomy of operation will be allowed. A change in pilot intent would, of course, be reflected into appropriate and coordinated potential changes in individual function executions. Allowing autonomy at this level simplifies the implementation (and also the test) of the system. It further allows much faster reactions to changes in the environment since the decisions can be made region by region rather than centrally. Artificial intelligence may also be needed at this level to determine the best weighing of information and to determine the best course of action, within the constraints of the higher level objective.

Additional lower levels of control may similarly be required, each operating within the constraints imposed by the intent and goals of the next higher level. Operation of the avionic system in a sense parallels that of a well honed military command structure which allows subordinates freedom of action within the constraints of the objectives provided by their superior officers.

A common family of executive software and executive control structures will be used to support all of these levels of operation. Commonality in software modules will be similar to the commonality in hardware modules discussed in the section on physical architecture. A family of executive and control structure modules can be well tested with the needs of any individual decision level being accomplished reliably by an appropriate set of software modules.

The control system architecture in an advanced avionic system will also rely heavily upon extensive on-board self test of software and hardware to ensure reliable operation and to support on line reconfiguration to improve aircraft availability. The standard hardware modules with multiplex interface between modules are particularly well adapted to complete, on-line self-test. First, the many thousands of interconnects which exist in conventional avionics are eliminated, which directly reduces the scope of module self-test. Simplified interface equates to simplified, more comprehensive self-test. Second, multiplex lends itself to end-to-end testing with a pulse-by-pulse self test for 100% confidence. Third, large scale and high density integrated circuit technology makes it possible to provide special self-test chips that can be utilized in each standard module.

Since testing is performed during flight, intermittent failures are detected and isolated in the environment in which they occur. Most CNDs and RTOKs are eliminated. In addition, the built-in test capability of the modules and the advanced multiplexed communications make it practical to provide on-line, hot spares for many critical functions. Such spares not only permit systems to heal themselves after failures, but may also allow maintenance deferral. If a system has corrected a failure, the urgency to replace failed modules between missions is reduced. Finally, the test capabilities provide the maintenance personnel with fully automatic identification and location of failures, thereby enabling rapid line replacement of failed modules.

CONCLUSIONS

Appropriate architectural approaches in the physical, functional, information transfer, and control system areas are the key to future avionic capabilities. The appropriate architectures will provide dramatic improvements in system performance while simultaneously improving system availability, supportability, and affordability. The software and hardware technology required to achieve these architectural improvements are already here and simply need to be improved, properly applied, and integrated. The resulting weapon systems will, however, have widespread effects in many areas of operations, logistics, and equipment acquisition. Changes will be required in the way pilots are trained and conduct their missions. The proper pilot/vehicle interface will need to be developed to fully allow the pilot to act as a system manager. At the same time data must be provided to assure pilot confidence that the automated system is accomplishing properly the detailed operational tasks which were formerly accomplished manually.

Procurement of avionic systems and spares will undergo a dramatic change. Industry product lines and alignments will change. Government procurement policies will be altered. Common modules will likely be procured directly by the military from software and hardware module sources and will be provided to avionic vendors. Avionic systems developers will find themselves creating special sensor and effector modules and function-unique software to be used with modules common to many other uses. Because most functions of the Avionic Intermediate Shop will disappear, the large organizations now associated with this function will be greatly reduced. With large numbers of throwaway modules, ~~the~~ depot repair facilities and organizations will shrink, or the function will revert to the original manufacturer.

These changes can provide far more Air Force fighting power per dollar. The task is technically achievable. The challenge is to break free of the comfortable post-World War II path of avionic design and support. Instead of incremental applications of advanced technologies with incrementally small improvements, a revolutionary and concerted technology application to gain a decisive advantage should be made. The future of Air Force effectiveness is in the balance.

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DISCUSSION

F.Broecker, Ge

Does an improved Avionics Architecture, which you advocate, bring any relief as to the development and substantiation of the functional requirements/specifications before it is transformed into computer language and algorithms?

Author's Reply

Partially; the new architecture will not help to decide what functions are needed or how they are specified. It can, however, make early evaluation of the validity of those functional requirements easier since the hardware, architecture, language, and interfaces are known beforehand. The functional uniqueness resides in the algorithms and software. Thus, the unknowns are considerably reduced in development and substantiation.

F.Broecker, Ge

In case the extent and importance of the functional requirements/specs are unchanged with the current extent, is there any other simplification/relief that justifies the statement that the software is simpler and cheaper with the new architecture?

Author's Reply

The software is simpler and cheaper because most of the system will be combinations of a few common modules and library software, with only the function-unique software to be implemented and tested. This regularity is also amenable to automated software procedures. In addition, designing software functionally, to operate by expression of intent, decreases module connectivity making individual software modules easier to write and test.

M.Burford, UK

While it is true that more and more relatively inexpensive and powerful hardware is allowing the development of computers with "reasoning" capabilities, is it not true these developments are more likely to cause a shift in the emphasis of the software role as opposed to a revolution? As the software firms up into hardware, the task of the software component will be relieved of the more mundane activities. This will surely not have the net effect of reducing the software components role, but will allow it to concentrate on the more difficult to implement executive type of decisions, such as exception handlers and data presentation editor.

Author's Reply

The software role is indeed more evolutionary as opposed to revolutionary versus the revolutionary increase in hardware capability and architecture. Some "revolution" is needed in software, however, in the way applications are partitioned. "Intent driven" operation, for example, is a significant departure from current practice. Other software revolutions will come in computer automated software development, documentation and maintenance.

We don't see that the "software firms up into the hardware" (firmware) to any greater extent than now, but that the hardware will be "non-specific" until loaded (minimal micro-code/firmware). For routine functions, common modules and library software will constitute a large part of the system. This will not have the "net effect of reducing the software components" but of increasing it, but in a positive sense overall. The hardware/software rebalance will more likely come in automated procedures and a reduction in the percentage of time devoted to software maintenance.

W.McKinlay, UK

It is agreed that systems have evolved so far but perhaps the revolution required is a proper unacceptable constraint to use a bus connecting function module because of the major changes in function permitted by later technology and the technology dependence on sensor characteristics. How can standardization be made to pay off without making some of the desired system features impossible to achieve or without, in practice, making subsystems more extensive or difficult to develop to the desired performance?

Author's Reply

The goal of this architecture and its interfaces and modules is to anticipate future requirements in such fundamental parameters as data flows, bandwidth, operations per second, etc., then to implement in the modules what current technology will support. As the technology changes, the new technology will change only the number of modules required per function, and the system will be transparent to that change. The bus interface at the functional cluster level is not a factor in taking advantage of technology (major technology advances have been made in the F-16 system without abandoning the basic MIL-STD-1553 interface). While it is true that the performance, especially in the sensor area, is technology dependent, a properly designed architecture should be transparent to those changes. A Standard that does not have this technology transparency is vulnerable to being superseded in any event.

TACTICAL REQUIREMENTS IMPACT ON AVIONICS/WEAPON SYSTEM DESIGN

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SUMMARY

The complexity of tactical weapon delivery has been greatly increased by the advent of new weapons, the enormity of enemy air defenses and the awesome capability of new digital technology. However, careful assessment of the tactical requirements becomes even more important if a truly effective marriage of airframe, avionics and weapons is to be achieved. A review of a typical tactical mission requirement, battlefield interdiction, establishes a base for derivation of functional requirements on which an integrated attack system architecture can be designed. The result is a need for a multi-sensor, multi-mode capability functionally integrated to achieve the flexibility required by the mission.

1.0 INTRODUCTION

When the British Royal Flying Corps in World War I conceived the idea of a fighter-bomber by installing four 25 lb bombs on a Sopwith, few foresaw the complexity of today's weapon/aircraft interface and the target environment in which the fighter bomber must operate. From this modest beginning into the 1950s, tactical weapons still consisted principally of guns and high explosive bombs, and anti-air defenses relied on guns of various caliber.[1] The advent of the tactical missile, air to air, air to surface and surface to air, brought about dramatic changes in both fighter bomber weapon control requirements and in the flexibility and lethality of air defenses. Through this period of change, tactical fighters have undergone an infusion of technology that leaves their flight performance and weapon control capability unparalleled. The question arises, however, do these awesome capabilities indeed permit today's fighter pilot to successfully destroy a determined enemy? Are the aircraft characteristics, weapon control system capabilities and the weapons truly compatible? Are the tactical requirements fully reflected in the total engagement system design? There is no clear cut "yes" or "no" answer to these questions. However, it behooves the systems designers to critically examine where we are and where our future systems must go. Airframe designers may lean in one direction, weapons control system designers in another and weapons designers yet a third direction. Yet on one point all will probably agree -- the next generation must be an integrated attack system featuring multi-sensors and a wide range of modes to meet the difficult tactical weapon delivery requirements.

However, this integrated attack system must be a departure from the popular conception of "integration". No longer can a system architect assemble a group of "elements" with given performance characteristics and "integrate" them through some common processor and achieve the maximum capability of the system. Today's requirements dictate that each "element" (in the case of weapon control usually sensors) must be designed with full knowledge of its role in the integrated system. Software must reflect an understanding of the multi-mode, multi-role functions required to achieve detection, acquisition, tracking and delivery compatible with a wide range of weapons. Shared processing and shared apertures will be common. Stealthy operation imposes stringent demands on control of own emmissions and judicious use of the enemy's emmissions. But as a bottom line, the capabilities incorporated in the system must not be allowed to proliferate to the extent technology will bear but must be carefully matched to the tactical requirement to be fulfilled.

This paper looks at a pressing tactical requirement -- destruction of enemy armored forces in the second echelon. It examines the functional requirements derived from these operational considerations and matches them with the elements of weapon control needed to perform the functions. Finally, the techniques of integration and the impact of technology are discussed.

2.0 TACTICAL REQUIREMENTS

As an illustrative example of the impact of tactical requirements on weapon system design, the battlefield interdiction mission or destruction of enemy armored forces in the second echelon, has been chosen.[2] The most important aspects from a system design standpoint are the characteristics of the targets, constraints in acquiring the target, how to get to and depart from the target area, the weapons involved and, the most elusive of all, the tactics required to get the weapon on the target[3], which is often integral with getting to and departing from the target area.

2.1 Target Characteristics

It is not sufficient to just characterize the target in terms of its radar cross-section, IR emmissions or minimum expected velocity.[4] To derive functional requirements for the integrated attack system the physical characteristics, the vulnerable aspects, the modes of operation and deployment are all important inputs. In this example, the targets are not only tanks but self propelled artillery, armored personnel carriers, trucks and mobile air defenses.[5] The fact that they are metal, are physically large, radiate heat when running, are camouflaged, all are important in choice of sensors. Since the purpose of the second echelon is to exploit first echelon breakthrough, the likelihood that the targets will be on the move, on the roads and, for tactical control, in proximity to one another is high. RF emmissions from the gun/missle defense radars and from communications is a likelihood.

2.2 Expected Constraints

The highly sophisticated and effective enemy air defenae environment is the principal constraint on integrated attack syatem design.[2] The attacking aircraft must fly very low and very fast to survive.[6] This brings to bear other complications for target acquisition. Terrain masking now becomes extremely important. Armored forces proceeding down the center of a 200 meter roadway with 10 meter high trees on either aide presents a six degree mask to an attacking aircraft. If the aircraft is at 70 meters altitude, the target will not be within the pilots line-of-sight until he is only about 670 meters away or, at 244 metera/sec airspeed, about 2.75 secs from the target. An alternative to increase the line-of-aight range ia to pop-up to a higher altitude with the attendant risk of greater exposure to enemy defensea. Also the terrain presents problems for ingress and egress to the target. The speed and altitude dictated by the miasion impact the terrain follow/terrain avoidance requirements.

Night and weather conditions are also constraints since this mission requires the system to contend with both. Choice of frequency for the sensora is impacted by the severity of the weather requirement at low altitude. Background clutter is also a constraint. The multi-sensor mix and particularly the multi-mode requirement on each aensor is impacted. Signal procesaing requirements are alao vulnerable to the kinds of backgrounds expected. Overlaid is the significant progress made by the enemy in Electronic Counter Measurea (ECM) and Electronic Counter-Counter Measures (ECCM) which will make his defenaea even more difficult to penetrate.[22]

2.3 Weapon Selection

In the end, the weapon ultimately dictates the syatem design. For destruction of enemy armor,[7] the moat effective weapons currently in the free world inventories are cluster munitions,[8] line-of-sight missiles [9] and guns. Cluster munitions are delivered as area weapons and, if delivered from low altitude, usually require overflight of the target area. Most current line-of-sight misailes are not launch and leave, therefore require that the target be illuminated until the missile impacts. Guns, of course, require closing to a short range for maximum effectiveness. All of these weapons, therefore, require that the target be within the pilots (or sensors) line of sight at launch.[10] Weapons projected for production will have launch and leave capabilities,[11] and may be launched both offset to the target and without line of sight at time of launch. These characteristics will obviously impact heavily on the syatem requirements. Where currently minimum launch range, line-of-sight needs, and illumination requirements dictate acquisition ranges and targeting accuracies and resolutions. Removal of theae constraints will bring new sensor modes into vogue and change requirements drastically.

2.4 Target Area Ingress/Egress

Of even greater impact on functional requirements is the problem of getting to the target area and returning. It is obvious that in face of the expected enemy defenses that ingress and egress would be expected to be at low altitude with high speed.[12] In addition, this capability would be required at night and in all weather. Impacting on the design is the expected terrain including wire and tower avoidance. The navigation accuracies to reach cued target coordinates are quite high requiring accurate Inertial Navigation System (INS) update. The expected mission times, while not as long as deep interdiction missions, are still significant in terms of expected INS errors. Also of considerable impact is the requirement for multiple modes during ingress/egress. For instance, requirements for air-to-air search along with terrain follow and navigation update are considerable loads for a radar. The interleaving of modes within a sensor or among sensors is a critical issue dictated by the users requirements.

2.5 Other Mission Impacts

Choosing the battlefield interdiction mission as an example of how tactical requirements should influence weapon system design does not ignore the impact of multi-mission requirements on tactical aircraft. Obviously all mission requirements must be assessed in the same manner with inevitable compromiaes in design. The thrust in this paper, however, is to insist that compromise in design be determined by total requirements assessment.

3.0 DERIVATION OF FUNCTIONAL REQUIREMENTS

The functional requirements for the avionics of the tactical aircraft are driven by the missions to be performed by the weapon aystem. Since most current tactical aircraft and likely most future aircraft will be required to perform an even wider variety of missions, the functional requirements are expansive while demanding precision in many segments of the mission.

3.1 Mission Timelines

A typical tactical air-to-ground mission profile as shown schematically in figure 2-1 imposes requirements vastly different for each segment of the mission with the greatest avionics load uaually occurring at or near weapon delivery. A wide variety of such timelines exist for the typical tactical aircraft.

The avionics system related functions associated with each miasion segment for the ground target attack mission are shown in table 2-1. For mission success the avionics systems must be capable of providing timely data with the accuracy demanded by each mission segment. The type of terrain, the enemy defensive posture and the compliment of weapons to be delivered influence the performance level required of avionics systema.

Various levels of activity will exist within each mission segment as well as between mission segments. Crises may precipitate high activity levels during mission segments which normally are quiet, especially if multiple anomalies or failures occur simultaneously. It is during the peak activity periods that the real stress of the man and the machine becomes apparent. Thus the avionics as well as the airframe and weapons must be organized to maintain stability during periods of intensive pilot attention to a distracting occurrence which may temporarily consume his activity. Mission success may frequently hinge upon being able to cope with crises since the enemy will try to make life difficult for the attacker.

Table 2-1 PRIORITY OF FUNCTIONS TO BE ACCOMPLISHED DURING GROUND TARGET ATTACK MISSION SEGMENTS

Function/Mission Segment	Taxi	Climbout	Dash Cruise, Loiter	Descent at FEBA	Penetration	Search & Acquisition	Attack & Guidance	Exit
System Missionization	2							
System Checkout & Test	3	2						
Inflight Performance Monitoring			4	2	2	2	2	2
Communications	1	3	3	5	5	8	8	6
Navigation		1	1	3	3	3	3	3
Terrain Follow & Avoidance				1	1	1	1	1
Airborne Target Search & ID		4	2	4	6	7	7	5
Threat Detections					4	5	5	4
Ground Target Detection & Track						4		
Weapon Delivery							4	
Detection of Targets of Opportunity				7	6	6	7	

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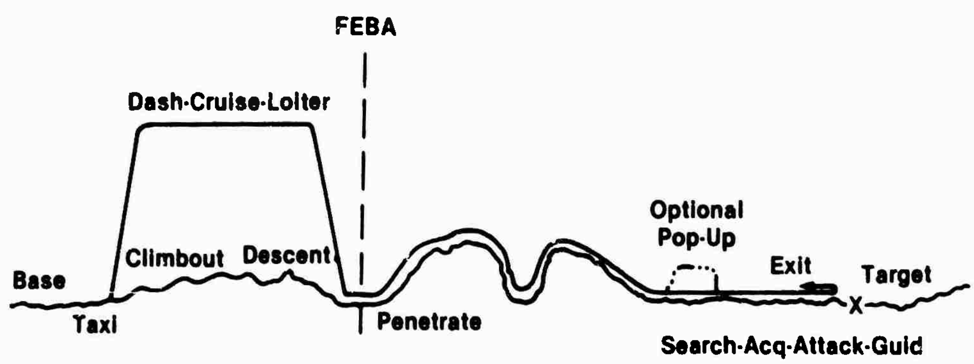

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Figure 2-1: AIR-TO-GROUND TARGET ATTACK MISSION PROFILE

The mission timeline requires careful system design and mission planning since it will continue to unfold endlessly as the mission progress, never pausing to let the system or pilot catch up. The mission segments must allow for periods of adjustment and must compensate where possible for temporary sensor or pilot lags which may occur becauae of this continuing evolution of the mission timeline. Planning relaxed timelines at the peak load period becomes difficult of course because the peak load period place severe demands upon the system.

3.2 Accuracy/Resolution Computation

The system accuracy requirements change depending upon the system function being provided. The ability to adjust the system to the requirements of the current function is desirable to optimize the utilization of sensor and computational assets. This, however, may be unachievable because of hardware inflexibility. Some computations may be characterized by inaccuracies due to long periods between data points, others by frequent data points which individually have sizable measurement errors.

A primary function of the aircraft avionics in all missions is that of navigation. The navigation requirements range from several kilometers when flying over water because of the long intervals between updates without external positional data, to a few meters where frequently updated positional data is provided by highly accurate weapon delivery sensors. In general the navigation error corrections should be made quickly as long as the uncertainty does not place the update point out of range. With maps created by on-board radar or IR sensors or external navigation aids such as satellites, navigation system update should provide location determination to the accuracy required for flying a predetermined course.

For interdiction and target acquisition the navigation requirements are much more severe for low altitude operations than for flying from point to point at high altitude. Blind delivery of weapons which do not have their own terminal seekers increase the navigation system requirements even more.

The most difficult task for the avionics system in the segment immediately preceeding weapon delivery is detection of the target and focusing the weapons system's attention on the target for the attack. In the air-to-air engagement this target cueing event is usually characterized by achieving a ratio of target signal relative to the background noise which permits detection. In the air-to-ground engagement the event is characterized by the target becoming discernible from the background clutter or the elimination of terrain masking of the target. In either the air-to-air or air-to-ground case the time available for weapon release tactics and delivery has a practical limit imposed by the point in the mission where target detection and cueing occurs.

The accuracy of target cueing will determine whether the right target is attacked and the proper decisions concerning the attack are made. The accuracy is twofold. It is concerned with the exact angle and range of the target and the correctness of the detections being truly a target. These accuracy requirements grow more critical as the urgency of decision grows.

The accuracy and resolution requirements for the avionics used in weapon delivery depend upon the type of weapon being delivered. A weapon with a terminal seeker for instance, has a reduced requirement for delivery precision over an unguided weapon since the terminally guided weapon will remove the weapon delivery system launch errors within the limits of the weapon's guidance system. This requires the weapon delivery system to be matched to the weapons used for the particular mission. It must be compatible with the targeting requirements of each weapon carried on each mission. In past systems this accuracy requirement has been built around the most severe targeting requirement. Future systems, with their software flexibility, may provide a degree of adaptibility which allows the targeting accuracy to be matched to the accuracy requirement of the weapon to permit the avionics sensors and processors to better service the other tasks being performed simultaneously. The dynamics of the target and the weapon delivery approach to the target also enter into the avionics system requirements because of sensor dynamic limitations and computational time lags.

Since identification of the target may be the major driver of system resolution and is usually necessary to establish tracking as soon as possible after detection, the system maximum resolution will likely be designed around this requirement. In all cases, however, it is desirable to attempt to match the resolution requirements to syatem needs at each phase of the mission. The resolution requirement should be matched to the mission phase to allow the computational resources to be focused upon the solution of the entire problems rather than on a limited relationship in which the processing inflexibility generates a resolution greater than required by the system. Resolution should be adapted to the system requirement where the resolution requirement is a variable throughout the mission and computer processing determines resolution.

3.3 Mode Determination per Mission Segment

A variety of system modes are required to accomplish the various segments of the missions. These system modes place modal requirements upon the avionics/sensors supplying data for the modes. These system modes are driven by demands and constraints placed upon the system by the engagement environment, mission tactics, airframe limitations/capabilities, avionics limitations/capabilities, weapon requirements, and pilot desires/abilities. The successful weapon system of the future will be designed using a balanced consideration of all of these factors to provide the flexibility necessary to accomodate all segments of the missions. Based upon the broad functions described in the previous paragraphs the avionics/sensors are required to provide categories of data which become system or sensor modes. These data may come from various avionic systems individually or in combination as dictated by the system mode demands and constraints.

Both radar and IR ground mapping modes as well as system modes derived from combined sensory and stored data will be available in future aircraft. These modes will permit ground mapping for day/night all weather navigation and targeting. For high altitude navigation the terrain maps may have coarse resolution since large landmass features will generally provide adequate navigation accuracy. For low altitude navigation the resolution requirements will likely be more severe since the terrain masking may severely restrict mapping range. This masking limitation encourages spot mapping for correlation with a data base for navigation update. The processing requirements for navigation update will range from the simple manual position fix with keyboard inputs to sophisticated correlation of multiple sensor data with a stored data base. In a single mission it is possible that both high and low altitude navigation segments will occur. Thus the avionic system must be adaptable to the navigation needs throughout the mission and the special requirements of each mission segment must be met.

Terrain Following and Avoidance allows all weather, day/night low altitude penetration permitting the aircraft to survive in enemy territory and return safely to fight again another day.[13] This capability requires frequent terrein data inputs from sensors which can detect the terrain contour as well as isolated obstacles such as redio/tv towers and electrical power lines end is influenced by the terrain features, enemy defenses and the mission being flown.[14] The terrain following can be mechanized to use reel time data from e multimode sensor to generate commands to the aircraft for mainteining an eltitude offset and avoiding obsticle. Terrain Avoidance, however, will likely require date of greater range than available from the real time sensor data being generated from a low altitude in hilly or mounteinous country since terrain masking will severely limit the sensor's range. In this case a stored data base augmented with real time sensor data is desirable.[15] The choice of sensors will be dependent upon the expected sensor performance under existing conditions and the availability of the sensor to provide terrain follow or avoidance while providing other modes for the mission execution. Since safety of flight is a predominate consideration the terrain following or avoidance mode will have priority over many other mission modes both in terms of sensor selection as well as interruption of other modes for terrain data collection. This will require cereful sensor management and control when the terrain following or evoidence mode is exercised in conjunction with other mission modes.

Mission variations have an impact upon target detection since the mission will establish the eltitude from which the detection must take place and the maneuver dynamics which occur during detection as well as the aircraft velocity during detection. In a typical ground target engagement the delivery aircraft will be likely to fly es low and as fast as possible taking maximum advantage of aircraft maneuvering for surviability.

Searching for and detection of targets, whether in the visual, IR or radar spectrum relies primarily upon distinguishing the difference between clutter or beckground noise and the target. Since the volume to be searched in a finite time period has a great impact upon the system's deta processing requirements, the search volume must be matched to the targeting positional unknowns and the constraints imposed by the particular mission. The low altitude mission imposes severe time constraints for target search and detection requiring a minimum of deley between the target unmasking and detection. This in turn restricts the search aree since the detection delay is essociated with the time required for the scenner to pass over the target area. This is established by the scan pattern and dwell time requirements of the sensor. The dwell time requirement, in turn, is established by the sensor and target signature characteristics and the data processing characteristics of the detection system.

Mobile target detection is simplified if ground moving target indication (GMTI) modes are employed. In missions which include moving targets the GMTI can greatly improve target detection range in clutter by isolation of the moving from non-moving targets or background. This can reduce the dwell time on terget in some cases thus improving the seerch field or detection delay required. This may also reduce the overall resolution requirement for detection since the separation of target from clutter or cencellation of fixed targets and background noise allows detection of moving targets without determination of target detail. The low altitude missions, as in the case of search and target detection, will restrict the target exposure time due to masking by terrain feetures. These low altitude missions will likewise impose search field limitations for GMTI at high velocity since dwell time requiraments will still exist.

When detected the target may need to be further clessified in some missions before an atteck can be made. This clessification may range from recognition by the target location to e more complex recognition due to specific target detail charecteristics. Here the mission requirements will strongly influence the target recognition mode utilized. Target recognition through detailed characteristics usually requires high resolution of target detail demanding long dwell times and extensive data processing. These requirements usually restrict area of coverage end frequently stress system thoughput end storage capabilities. Thus simplistic recognition should be used for missions where detailed target recognizers are not warranted. Multiple source deta, data from more than one onboerd sensor or data linked date from remote sources, may provide information which will allow recognition by positional locetion rether than detailed target cherecteristics thus eesing the onboard processing load. For instance, moving ground targets in the enemy 2nd echelon whether trucks or tenks may be vieble targets needing only to be detected in thet locetion identified from an external source as e 2nd echelon terget area. By contrast, in the close air support mission it might be necessery to distinguish the tenk from a truck to blunt an ongoing offensive since destroying the truck which is trensporting support equipment for the tanks might not heve as greet en immediate impact on the battle. The mission definition influences the degree of recognition desired end thus the recognition mode requirement.

The trecking requirements for eir-to-ground targets is dependent upon the mission, weapon, and target characteristics. Stetionary targets which are larger in size such es buildings, bridges, or dams may be trackad using an initiel designation by the pilot on the heed-up displey or on e sensor displey. An inertiel navigetion system updete will keep the eim point on the target. A moving terget, on the other hend mey require precise trecking since it has the cepability of changing direction or position. This may require an automatic trecking mode which is keyed to the terget extent or deteil within the terget.

The weapon impect upon the trecking requirements is through the technique it uses to destroy the target. An area weepon which uses a large number of submunitions scettered over e wide area to echieve its effect requires fer less from the weepon delivary system in terms of tracking then e laser guided bomb which guides on e leser spot creeted by the weepon delivery system. In the former cese positional accuracy of 30 meters or greater at the time of weapon launch may be adequate. In the latter case a continuous track from weapon launch to impact may be necessary with accuracies of 3 meters or less.

The mission requirements in terms of aircraft delivery altitude, speed, and maneuver constraints will drive those target tracking requirements associated with the target type and weapon type.[16] The mission planning phase will of course consider target and weapon type but the avionics systems must be able to cope with the dynamics of the aircraft in delivery for the weapons system to benefit from aircraft performance characteristics. Furthermore, the avionics system should be adaptable to the target and weapons types to permit the optimum sensor and processor utilization during weapon delivery and periods of maximum stress.[17]

3.4 Consideration of Other Aircraft Missions

Having selected the air-to-ground attack of 2nd echelon targets as the typical mission example for this document, we have not addressed the other missions which will be encountered by an all purpose fighter. These additional missions include the air-to-air and strike/reconnaissance missions. Both are important missions and warrant e brief examination.

The air-to-air mission is one which will be a part of the overall air-to-ground mission if the air-to-ground aircraft has self defense weapons and is responsible for its own anti-air defense. Although the air-to-ground fighter would prefer the air-to-air engagement on the return leg of his mission since the air-to-ground weapons would have been expended, the air-to-air engagement could come at any time. Thus the avionics must be configured to share certain air-to-ground and air-to-air modes at least to some limited degree. The major requirement is the ability to detect the enemy airborne threat and establish that an attack is eminent. The air-to-air mission may dominate when the threat is perceived to be real and evasive action is not desirable.

Whether the air-to-air mission is the major mission or evolves as a part of the air-to-ground mission, the avionics must provide for airborne search, detection and tracking functions necessary to deliver weapons effectively against the enemy aircraft. It is desirable to be able to detect the threat during air-to-ground activity before he has achieved a detection or at least before he is within the range at which he can launch weapons. After conversion to the air-to-air mode it is desirable to be able to search and track multiple targets simultaneously as well as to provide identification of all targets in the arena. The identification may be achievable only through cooperation with other aircraft or from ground stations although it is highly desirable for it to be an atonomous non cooperative system if achievable.

In the transition, when completing the air-to-ground activity while preparing for the air-to-air engagement, the demands upon the avionics will likely be at a maximum. Although the enemy may not time his attack to permit completion of the air-to-ground activity before the air-to-air engagement, it is desirable to be able to perform air-to-air multi-target search without abandoning the air-to-ground targeting activity. The accomplishment of the air-to-ground mission could depend upon a few more seconds of air-to-ground activity while observing the closure of the airborne threat. The management of the avionics to accomplish the simultaneous air-to-air and air-to-ground activity is a major task which has yet to be achieved in a current fighter aircraft.

Another complex mission from the standpoint of the management of the avionics as well as pilot work load is the strike/reconnaissance mission in which the fighter aircraft is required to search the battle area for targets for which no location is known and then destroy them. This is an extremely difficult mission because of the desire to fly low for survival in conflict with the requirement to fly at an altitude sufficient to detect targets over the terrain masking. It is extremely difficult in a single seat aircraft since a pilot has little time to interface with his sensors in such a mission because of the aircraft flying demands for a survivable engagement.

The reconnaissance segments of this mission requires periods of wide area searching which must be accomplished from altitudes sufficient to observe the possible targets over the terrain mask. Figure 2-2 illustrates the impact of terrain masking upon aircraft survivability. If we assume the mission is to destroy a typical gun site by detecting his location from beyond the AAA weapon range in a masking condition of 6 degrees (a row of trees 10 meters tall at 100 meters), the searching aircraft must fly at 300 meters altitude to detect the gun site beyong his range with no uncertainty of location. Assuming a 2:1 range uncertainty the altitude increases to 600 meters. Both altitudes are highly undesirable for survivable attack since a typical surface to air missile or another AAA gun battery with the same masking constraint could be launch an attack against the figher if within 3 kilometers.

The strike/reconnaissance mission places more stringent search and detection demands upon the sensor than the 2nd echelon prebriefed search mission used in the previous example for air-to-ground target attack. This is due to the greater detection ranges and search volumes. If self defense from air attack is also apart of this mission the avionics management problem grows even worse.

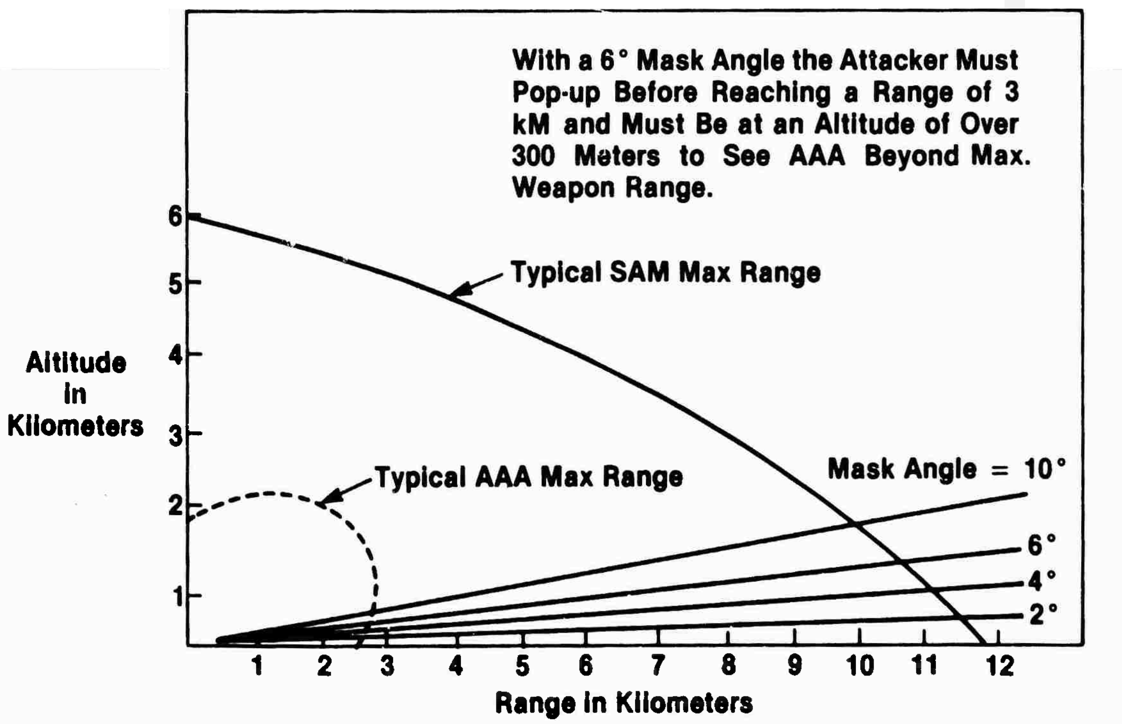


Figure 2-2: TARGET MASK ANGLES RELATED TO DEFENSIVE WEAPONS RANGE

4.0 SENSOR SELECTION

Current avionic sensors cover the full frequency spectrum with the lower frequency systems being primarily cooperative devices while the higher frequency systems are autonomous. Navigation and communication systems such as LORAN, the Global Positioning System and JTIDS can be used for aircraft positioning and location of cooperative targets. Higher frequency devices such as radar, radiometer, infrared and television sensors can be used for accurate relative position measurements as well as improved location when used with navigation or communications systems. Whatever the source of data the avionics system must be capable of data collection in battle environment. This environment often establishes the sensor utility for providing meaningful data during the various mission segments. The sensor selection is necessarily based upon the environmental constraints and the data requirements of the weapon system.

Because of its ability to gather data at night and under inclement weather conditions, the radar sensor has become a primary avionics subsystem in the modern fighter and bomber aircraft. Its short cominga include a limited resolution in both range and angle, the glint and the specular characteristics of the return. It has good long range capability and is adaptable to detection of moving targets. This makes it very useful as detector, tracker and (in some casea) an identifier of both airborne and ground targets. Its accurate ranging permits terrain following measurement and air to ground ranging. It has high resolution capability but may require significantly long looks at the target to develop this resolution through coherent integration. This allows radar maps geometrically comparable to photographic mapa to be generated for navigation, position update and targeting.

Because of its ability to generate vast amounts of high resolution data, the radar can stress the airborne data processing capability. For that reason, the mode configurations and utilization must be closely matched to the mission requirements throughout all of the mission segments to prevent system overload. The radar sensor must be programmed to provide timely data in the multiple modes executed to fulfill the mission. With modern digital processing the radar can be configured to provide data for a wide variety of modes. With electronic beam agility the radar can simultaneously provide navigation, terrain follow, target tracking and weapon guidance functions in adverse weather and at night when neither the unaided pilot nor other avionics sensors are effective.

The target's emissions can be used to identify and track the target in angle. (Passive range tracking is possible but difficult). This allows for passive attack or long range detection if the target is emitting. This enhances the element of surprise and aids in detection of enemy threats. As in the case of radar, the passive RF sensors have day/night all weather capability and can be big consumers of onboard data processing capability if a number of threats are present or the non target signal density is great.

Passive RF sensors can provide data unavailable from other sensors or data requiring complex, time consuming processing when derived from other sources. Because the angle data may be coarse and the range data time consuming to generate, the passive RF sensors may work best in conjunction with other sensors rather than functioning in an atonomous mode. Proper integration might allow these sensors to provide long range target identification and tracking as fire control inputs where radiating targets are a part of the mission. It is because of the unpredictable nature of the periods of radiation of such targets that the integration with other sensors is desirable.

Many missions may be performed in areas where or during periods when the weather does not prevent the use of infrared sensors. In these instances accurate detection and angle tracking of targets is possible using forward looking infrared sensors. As in the case of passive RF sensors accurate range tracking is more difficult to achieve. Again the integrated sensor system approach can provide range data through use of radar or laser ranging.

The infrared systems are particularly effective when detecting active targets which are emitting heat or have a temperature differential with respect to the surroundings. A match up of the infrared sensor avionics with an infrared guided munition is usually effective since both should work well in the same environment.

Lasers are very useful for ranging and target illumination for weapon guidance. For target tracking their narrow beam allows for good angular tracking and their short pulse capability allows for high range resulation. For target illumination the beam can be controlled to meet the spot tracking guidance requirements of the weapons. A laser radar can have a multiplicity of modes similiar to those of RF radar providing in some cases superior performance.

The short coming of laser systems is the impact of the atmosphere upon their performance. This limits the conditions under which the system will provide suitable range performance to generally fair weather. This of course limits the utility of lasers as a single sensor in many mission segments.

When used with other sensors in an integrated system, the laser can provide data unavailable from other sources. This is particularly important in short range engagements both air-to-air and air-to-ground when lasers may provide more usable tracking data than other sensors. As one element of an integrated multiple sensor target identifier the laser is important because of the detail it can generate about the target which has a different information content than the other sensors.

5.0 SENSOR INTEGRATION

The digital computer has brought about a revolution in the avionics design. The unique analogue processing embedded in each avionics subsystem is being replaced by digital processing hardware which is less unique between subsystems. In fact the community is attempting to impose commonality standards. As digitalization of subsystem functions progresses and commonality grows the opportunity for system performance improvement through functional integration will naturally evolve. To assure that this integration evolution brought on by the computer revolution is channeled toward achievement of the overall mission goals, the avionics, airframe and weapons must be thoughtfully developed. Sensor integration, flight/fire control integration, and weapon/airframe integration are the key areas for near term effort. This discussion focuses upon the sensor integration and its major elements of aperture sharing, the functional relationships and the processing commonality.

Because the radar was the first major avionics sensor on board a fighter aircraft requiring as much unobstructed view in front of the aircraft as possible and because it is still a primary sensor, the prime real estate in the airframe (the nose) is usually taken up by the fire control radar. The radar designers are experts in convincing the world that they can always use a larger aperture so that all challenges for nose real estate are defeated. As other sensors improve and radar antenna design evolves this radar dominance will subside. Shared aperture concepts will emerge.

What are the driving needs for aperture sharing? Visability is of course a major consideration. In addition there are no displacemeot errors if all the sensors are co-located. Furthermore, stablization can be simpler since there may be less movement between sensors' boresight lines and stabilization sensors if all are colocated. Data for the various sensors should be more easily correlated.

In the RF bands unique methods are being developed which permit wide band signal reception in conjunction with active radar to coexist in a common aperture. This permits data from a broad range of sources to be easily correlated in time and angle with the radar data.

In the visual and IR bands unique developments have provided data from two sensors to be gathered simultaneously with a common mirror system. This allows easy correlation of these data as well as laser data which may also utilize the common mirror system and aperture.

Many of the functions performed by the various sensors are common between sensors such as pointing functions. These fuoctions can be performed more efficiently if common techniques are applied. This allows for effective distribution of mission tasks between sensors as well as coordinated multiple sensor activity for joint tasks.

Since the list of modes each sensor can perform is long and highly overlapping under ideal conditions, the sensors may be required to hand off tasks which can be more effectively performed by a sensor which is not as fully utilized for a particular mission segment. These hand-offs should be configured so that as the system encounters less than ideal conditions, the tasks can be handed to the sensor providing the best data. This may require a redistribution of the tasks being performed by that sensor and trade-off between sensors of the mode sharing responsibilities so that the key functions are serviced.

This implies systems which can sense performance degradation in a particular sensor and which can manage their resources to compensate for these performance degradation. This is important both for good weapon system performance as well as safety of flight. The functions must be managed and monitored by each sensor system as well as managed and monitored by the integrated system cootroller be it manual or automated. Multiple sensor systems of the future which function in an integrated fashion will utilize the unique characteristics of each sensor to monitor the overall performance of the system. This will provide the data necessary for the various system modes under the variable environmental conditions under which the mission is executed.

The functions provided by the various sensors aboard a fighter aircraft are shown in table 2-2. The utility of these sensors is dependent upon the conditions under which the mission is being performed and the geometry of the engagement. These are the functions which must be managed in the integrated weapons system.

The overlap in modes available for the various sensors shown in the table indicates the redundency of processiog required within the weapons system. If the sensor processors are autonooous this redundancy necessarily exists. The integrated sensor processor of the future will combine many of these redundant functions by using common processing where possible. Some redundancy may still exist since more than one sensor may be performing the same function during transition periods. The common processor will organize this processing so that these redundant processes are performed more efficiently.

There are many advantages of common processing even without one computer performing all like functions. By merely having like processors in the various sensor subsystems the common functions can be serviced with common software which will reduce system design time and improve the understanding of the system by maintainence and repair personnel because there are fewer different software elements to deal with.

For those functions that are unique to a particular sensor there are efficiencies associated with common architecture between sensor processors. Here again the maintainence persoonel will more readily understand the system software and hardware since there are likely to be many similiarities in these unique functions.

As the integrated sensor systems emerge, the occasions for a separate expert for repair of each

TABLE 2-2

SENSOR UTILIZATION IN THE FIGHTER MISSION

Visual	-Target Acquisition and Track -Navigation & INS Update -Target Identification -Weapon delivery via HUD or in cockpit display
Radar	-Target Acquisition and Track -Navigation Fixtaking & INS Update -Map Correlation (DLMS) -Moving Target Indication & Tracking -Ranging -Weapon Guidance -Aircraft Guidance -Target Identification
E/O	-Target Acquisition and Track -Image Magnification & Identificatioo -Navigation Fixtaking & INS Update -Map Correlatioo -Ranging -Laser Guidance
ESM	-Threat Warning & Avoidance -Target Acquisition and Tracking -Target Identification

sensor processor begin to diminish. Although the processing associated with each sensor may be separately identifiable in the integrated system software and/or hardware, an overall understanding of the whole system becomes of greater importance to isolate problems in modes using data from multiple sensors. Common computer languages such as Ada are emerging and will help to provide system commonality of processing. Commonality of sensor hardware components has been a stated goal in military hardware for many years. Commonality of processing hardware is a more recently stated goal. Commonality of software is as yet unachieved and will require several more years of "organization" before it becomes a reality in military systems. We should at least try for common processing within the systems designed for future use. Without such a thrust the task of system integration becomes very difficult, inefficient, and in all likelihood ineffective.

6.0 IMPACT OF TECHNOLOGY

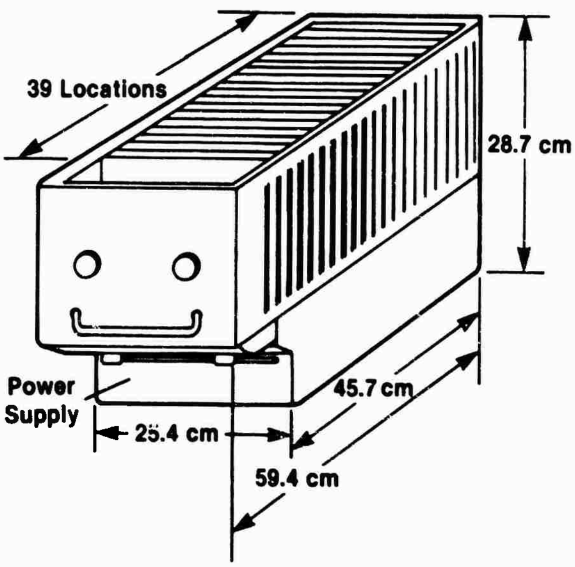
Today's digital avionics systems are but just a beginning of the technological advances to become available in advanced aircraft of the future. We have succeeded in the conversion of many analog avionics devices to digital devices. The next step is to upgrade those devices to take advantage of the new high speed digital capability which has emerged in the 1980's.[18]

Twenty five years ago we built rooms or buildings to house the new digital computer that could compute the company payroll overnight. Today we use microscopes to design the devices which will make up computers the size of a cigarette pack which can process many orders of magnitude more data. This explosion of very high speed integrated circuit technology will permit the future avionics sensors to provide many more functions of greater accuracy and reliability than exist in todays most advanced fighters.

The programmable signal processor (PSP) of the 1983 fighter aircraft radar is a good example. The baseline PSP shown in Figure 2-3 is available today for performing the radar data processing functions necessary for providing the radar modes in a present era fighter. This processor is capable of a wide variety of modes including multiple target track while search for air-to-air engagement as well as terrain following for low level penetration for air-to-ground engagements.[19]

As very high speed integrated circuit technology becomes available in the latter part of the 80's this same PSP could be reduced to 1/4 the volume while still maintaining the capability to process the radar data of the current PSP (baseline). As shown in figure 2-4 the power requirement would be reduced by 1/7 and the reliability improvement would allow an increased expectation of mission success using the advanced PSP over the present configuration. Acquisition and logistic support costs would be significantly reduced.

But the radar will likely change considerably by 1990 so that the PSP requirements will be expanded to accomodate electronic radar beam steering as well as a multitude of new radar modes for enhanced air-to-air performance as well as greatly expanded air-to-ground capability. Figure 2-5 indicates the future fighter aircraft radar PSP characteristics encompassing the greatly expanded capability required for the advanced tactical fighters of the 1990's. By this time period the number of functions per chip will have increased so that even with the greater processing requirements the chip count is more than



(1) Chip Count · 5950

(2) No. of Board Pairs · 31

(3) Power/Volume · 2.8 kW 0.04 m^3

(4) Signal Processor Capability
— 16 MCOP (COP = 4 Mult, 6 Adds)

(5) GP Computer Capability
— 1.3 MIP (Dais Mix)

(6) MTBF (Fighter, Non-inhabited) · 330 Hours

(7) Acquisition Unit Costs · 100%

(8) Logistics Support Costs · 100% (3 Level)

(9) Probability Mission Success* · .994

(10) Development Cost Factors ·
- None (Baseline Reference)

*2 Hour Mission

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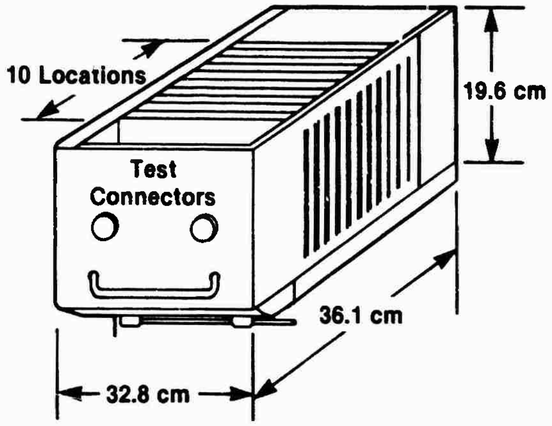
Figure 2-3: STANDARD 1983 FIGHTER RADAR (BASELINE) PROGRAMMABLE SIGNAL PROCESSOR CHARACTERISTICS



(1) Chip Count - 600

(2) No. of Board Pairs - 6

(3) Power - 400W

(4) Signal Processor Capability
— 46 MCOP (COP = 4 Mult, 6 Adds)

(5) GP Computer Capability
— 3 MIP (Dais Mix)

(6) MTBF (Fighter, Non-inhabited) - 2067 Hours

(7) Acquisition Unit Costs - 33%

(8) Logistics Support Costs - 9.3% (2 Level)

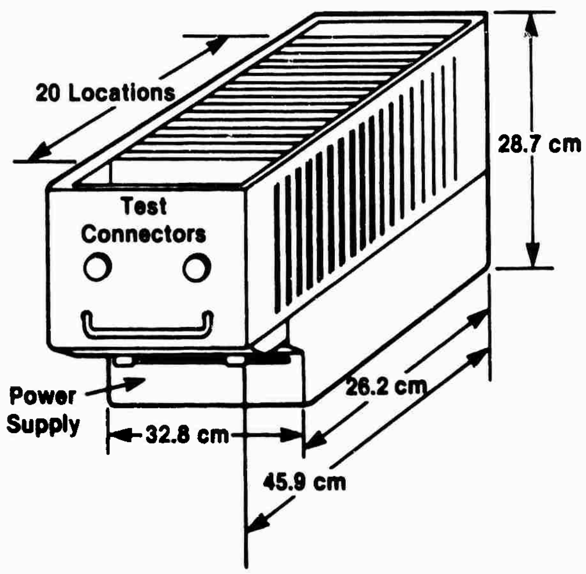
(9) Probability Mission Success* - .9990

(10) Development Cost Factors -
- Software Reprogrammed in ADA

*2 Level Maintenance
(No Redundancy)

83-0228-BA-6

Figure 2-4: BASELINE PERFORMANCE WITH VERY HIGH SPEED PROCESSOR



(1) Chip Count - 2200

(2) No. of Board Pairs - 17

(3) Power - 1 kW

(4) Signal Processor Capability
— 216 MCOP (COP = 4 Mult, 6 Adds)
— 32M BYTES Memory

(5) GP Computer Capability
— 6 MIP (Dais Mix)

(6) MTBF (Fighter, Non-inhabited) - 406 Hours

(7) Acquisition Unit Costs - 66%

(8) Logistics Support Costs - 48% (2 Level)

(9) Probability Mission Success* - .995

(10) Development Cost Factors -
• Software

*2 Hour Mission

83-0228-BA-5

Figure 2-5: 1990 FIGHTER AIRCRAFT PROGRAMMABLE SIGNAL PROCESSOR CHARACTERISTICS cut in half. The complexity of the edded redar modes will significently increase the cost with software development representing e mejor cost driver. Historically the demands of the mission have exceeded the cepability of the weapons systems end it is unlikely that the 1990 fighter would contain a PSP which is of much less cepability than the maximum the stete of art will allow.

The enhanced digital processing capability allows revolutionary rader system technology to emerge. The major rader advancements will occur in the erea of beam forming end control. The hardware which creates the radar beam and processes it in the tactical fighter of the 90's will likely be all digital in nature.

Currently the beam is formed using an analog transmitter feeding an antenna array which shapes the beam via its mechanical dimensions. The beam is positioned with gimbals which tend to move slowly and possess a great amount of inertia. The fighter radar of the 90's may have digital beam forming, shaping and positioning mechanizations with antenna arrays made up of a large number of digital transmitting and receiving modules which are controlled from and feed their data to a programmable digital signal processor. Such a configuration would require no transmitter, receiver or gimbals as we know them in today's radar systems since all of these functions would be performed by the digital active aperture antenna modules.[20] The beam would be formed, shaped and directed electronically by solid state devices under digital control. The evolutionary process for achieving digital active aperture radar capability by the 90's is shown in figure 2-6.

This advanced configuration will permit a wide variety of modes to be structured in the radar software which when coupled with the high speed computational capability will provide a full complement of air-to-air and air-to-ground modes to be executed in an interleaved fashion. This will permit a variety of wave forms and beam positions to be generated during a single PRF for multiple mode data collection simultaneously. This will greatly enhance the weapon system performance and mission flexibility of the advanced tactical aircraft.

As the digital active aperture radar evolves several intermediate systems may be developed. Agile beam technology has already been demonstrated for bomber application and may be available for fighter application within a year or less. As the very high speed data processing become available, advanced modes will become possible for both gimballed and electronically agile radars. Hybrid monolithic active aperture technology may be available in the late 80's to provide the digital receiving array flexibility for interpulse receive mode interleaving as en interim to the fully digital active aperture rader capability. Each of these steps offer significent system improvement and will develop softwere modes which are applicable to future systems as the reder technology edvances.

The technology of lasers useful for tacticel aircraft application has been evolving repidly in the past decade. Lasers useful for renging and illumination for weapon guidence made their debut during the late 60's. In the 70's the airborne lesers were considered for broeder roles of navigation, terrain following es well as multiple missile guidence. As we progress through the 80's the use of lasers to provide many of the classical radar functions for air-to-ground weepon delivery will emerge. The lesers are, of course, limited by environmental factors such as fog, haze and smoke but since they are complimentary to conventional radar sensors and provide highly accurate air-to-ground as well as air-to-air pointing and tracking, lasers are being highly regarded as an element of a multiple sensor system for the complex missions of the future.

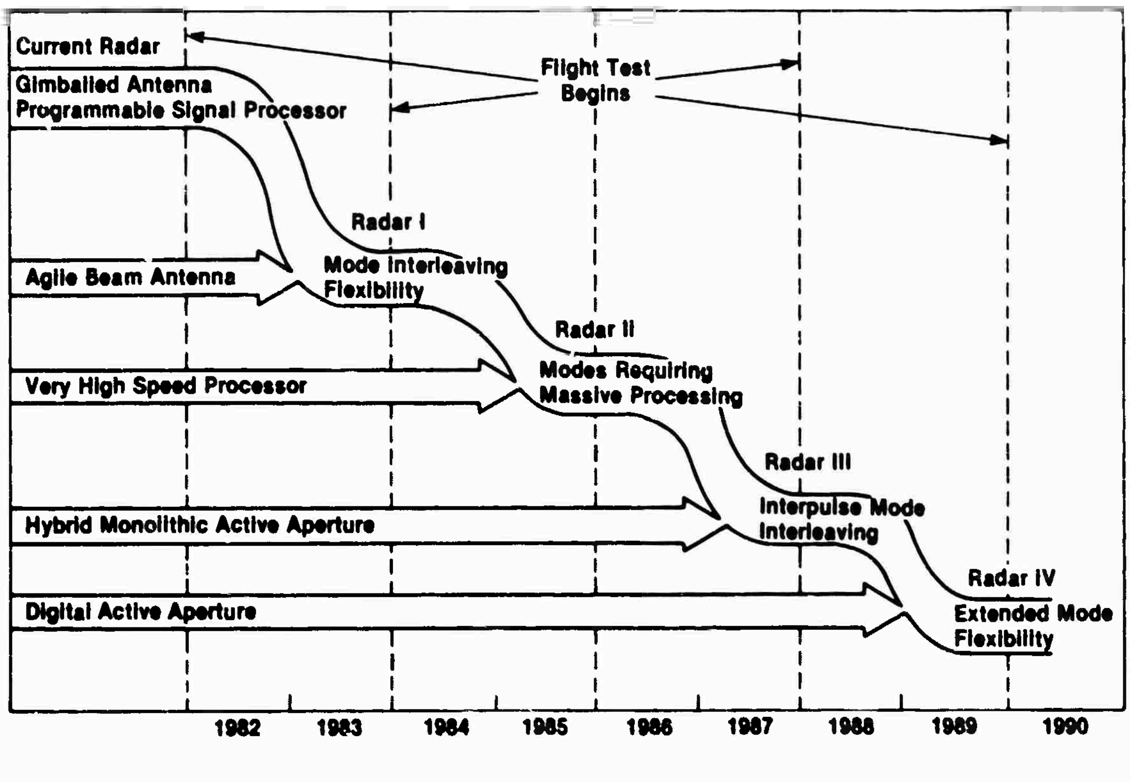


Figure 2-6: FIGHTER RADAR EVOLUTION

During the early days of laser development the emphasis focused around 1.06 micron region for target designators and laser rangers. This was compatible with TV optics and could be coupled through the same optical chain as the TV image to facilitate laser alignment. Current efforts are more heavily focused in the 10.6 micron region for better weather performance and compatibility with forward looking infrared systems operating in the 8-12 micron region. It is in this region that the significant developments in laser systems for the fighter aircraft of the 90's are likely to occur.

The CO_2 lasers can provide navigation, target detection, target classification, accurate pointing and tracking for weapons control as well as terrain following and obstacle avoidance. Since the laser system is compatible with the radar system in the data it generates as well as the format in many cases, the two systems can be used in supportive roles in the integrated system. Both the CO_2 laser and radar can provide reliable data for the conditions (weather, smoke, etc.) encountered in a high percentage of the missions. When these conditions degrade, the impact on the laser systems differs from radar systems. Thus, the compatibility changes from the selection of either sensor for distribution of the mission tasks between the sensors, to a selection of the best source of data for the existing condition. This will allow the CO_2 laser to be used during certain rare periods where rainfall degrades the radar and the radar to be used where fog restricts the CO_2 laser system. Weapons with guidance systems operating in the laser bands will of course be matched with the laser sensor systems for compatability of conditions under which the mission can be successfully executed.

A typical performance curve for a laser functioning in the terrain following mode is shown in figure 2-7. For a system which has a 7dB signal to noise the sensor could provide a 5 kilometer capability in haze dropping to about 3.3 kilometers in fog. This latter number being near the minimum range for safe high speed low level flight.[21]

Imaging infrared sensors offer enhanced fighter weapon delivery performance by providing both targeting and navigation data. In the 1980's it is likely that these sensors will be more heavily integrated into the fighter avionics suite for enhanced weapons system performance. To date these systems have been mounted in pods to aid in aircraft reconfiguration for specialized missions and to maximize the coverage of the sensors on airframes in which the nose is committed to other sensors (radars). By the 1990's these IR sensors will have moved to within the airframes of operational fighters and will providing multiple mode inputs for the integrated fighter control systems. This may impose multiple field of view requirements on the IR system as shown in table 2-3, which provide the variable sensing requirements of the full mission with a sensitivity to 0.1°C. This will yield a typical targeting system performance as shown in figure 2-8. The major improvements in the 80's will come from the detector technology which will provide cooled photo conductive arrays with the high sensivity necessary to meet the navigation requirement. These systems will be compact and reliable with digital output for direct interface with the system processor and other digital avionics. This enhances the ulility of the imaging IR as an important element in an integrated sensor system. The imaging IR when coupled to a CO_2 laser will provide functions such as navigation including INS update, air-to-air search, air-to-ground target search, moving target detection, target tracking, target identification and missile guidance. As in the case of the CO_2 laser the compatibility between the IR and radar will allow mode sharing between the sensor systems under favorable weather conditions and a hand-off to the sensor providing the better data under degraded condition.

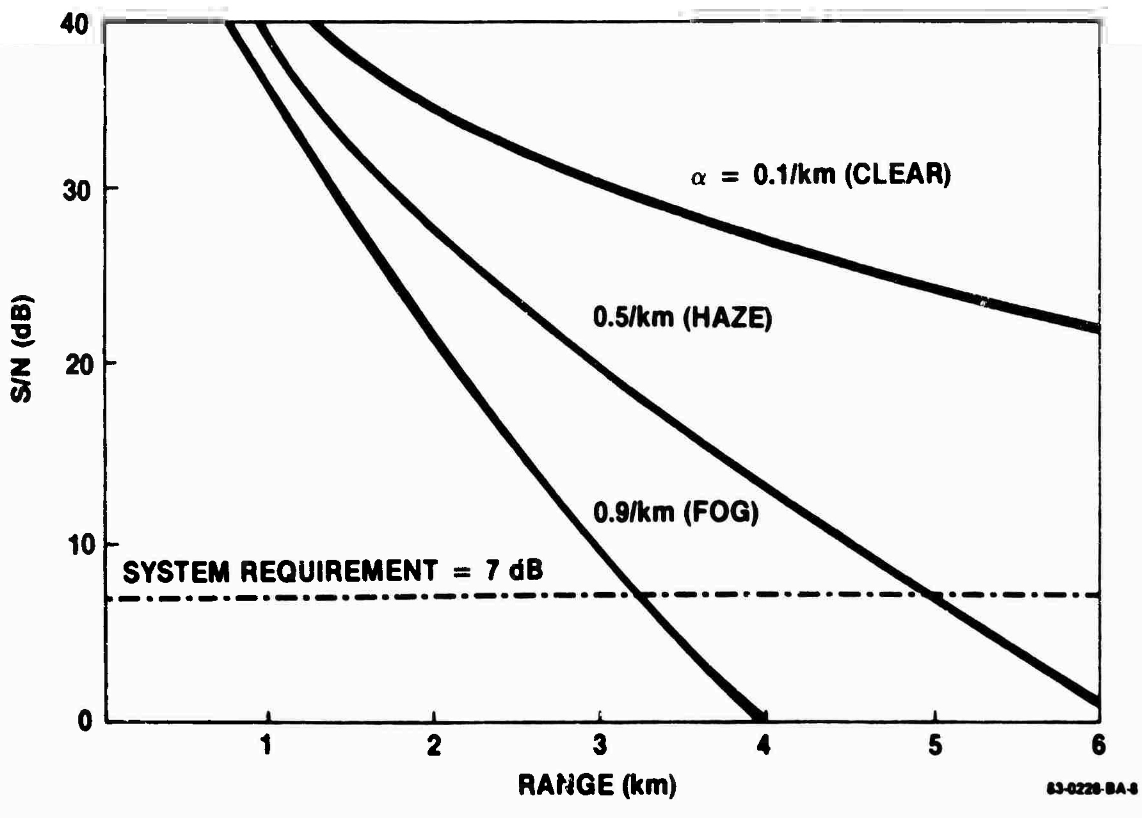


Figure 2-7: CO_2 LASER RANGE PERFORMANCE PREDICTION IN TERRAIN FOLLOWING MODE

Table 2-3 PERFORMANCE PARAMETERS FOR IMAGING INFRARED SYSTEM

	TARGETING FLIR		NAV FLIR
Effective focal Length (cm)	20.3	10.2	2.2
Field of View (Deg)	2.25 x 2.25	4.50 x 4.50	21 x 28
Aperture (cm) 4.0	10.2	5.1	1.1
f/#	f/2.0	f/2.0	f/2.0
Transmission	0.49	0.46	0.62
Instantaneous Field of View (Mrad)	0.15 x 0.246	0.308 x 0.492	1.43 x 2.29
Spectrum (microns)	8.1 - 11.5	8.1 - 11.5	8.0 x 11.5
Detector (mils)	1.25 x 320	1.25 x 320	1.25 x 320
Aspect Ratio	1 x 1	1 x 1	3 x 4

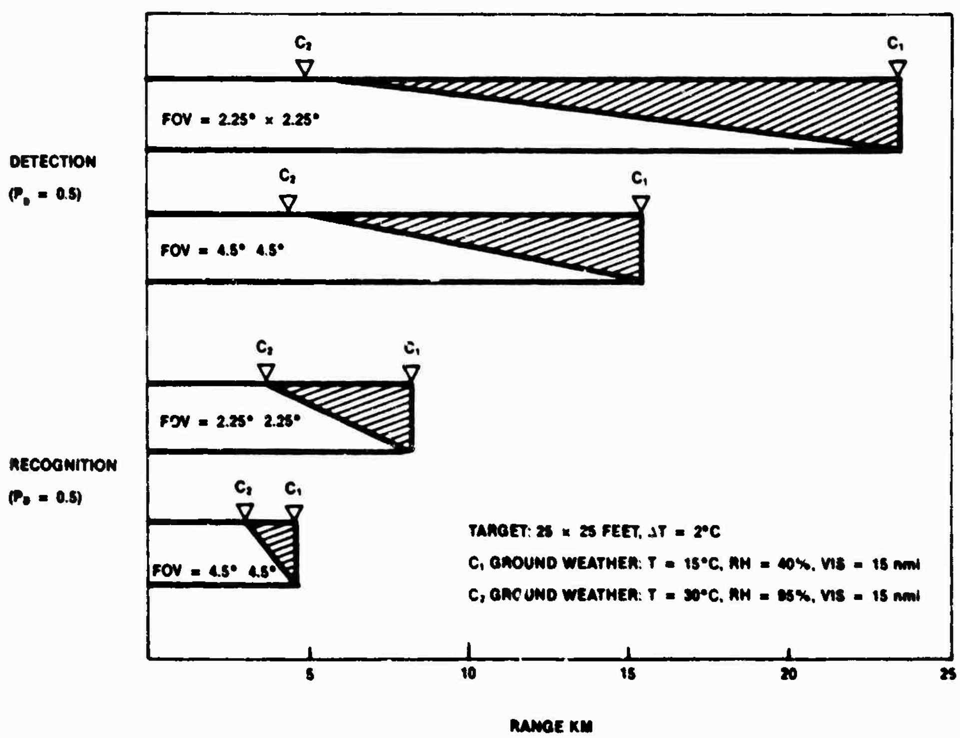


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Figure 2-8: FLIR AIR-TO-GROUND RANGE PERFORMANCE

7.0 CONCLUSIONS

Tactical weapon delivery systems for future tactical aircraft must be strongly influenced by the target characteristics, their environment and deployment, and by the weapons and tactics required to destroy these targets. The result is an integrated avionics system which exploits the flexibility inherent in digital technology and is integrated in function not just in hardware. To arrive at such a system architecture requires a methodical assessment of the tactical requirements to translate them into functional requirements from which a true integrated system architecture can be consummated.

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DISCUSSION

K.F.Boecking, Ge

In Table 2-A, it is shown that during ground attack the function TF/TA has a priority of 1 in the mission segments search/acquisition and attack/guidance. Would you please explain why the functions ground T/D and T and weapon delivery have a priority of 4 only considering that these functions were the reasons for take-off?

Author's Reply

The reason for assigning TF/TA priority No. 1 during all low altitude mission segments is because of the impact upon flight safety. Likewise, the system monitoring function must have high priority (No. 2) since it determines the quality of the TF/TA inputs for the system, thus the function is also key to flight safety. Navigation is a function that is always present throughout the missions and although the sensor suite of the aircraft may be fully occupied for a short period providing weapon delivery, a full awareness of where the aircraft is and where it is headed must be maintained. Thus, the weapon delivery priority of 4 during attack and weapon guidance means that it will be pre-empted if problems arise in the other 3 functions even though it's the primary task during that mission segment. A degraded mode in the event of TF/TA failure might be to fly at a higher altitude if tactically feasible. This would raise the priority of weapon delivery during the mission segments related to weapon delivery.

OPERATIONAL READINESS AND ITS IMPACT ON FIGHTER AVIONIC SYSTEM DESIGN

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I. ABSTRACT

Operational Readiness (OR) is a widely used term that covers various aspects of availability, maintainability, reliability and testability.

Just as the development of avionic systems require the establishment of system engineering, software design and interface management guidelines, the same requirement exists for the world of operational readiness. These OR guidelines include the following controllable elements:

Design-for-Testability (DFT),

Operational Fault Tolerance,

System Diagnostic & Reconfiguration,

Post-Flight Data Extraction/Analysis, and

Integrated Test & Maintenance.

Design and Acquisition of systems and prime electronic equipment must account for early consideration of testability and automatic test design requirements. Testability factors influence all phases of design, integration, deployment and support of electronic equipment and will adversely impact weapon system availability and ultimate return on investment if improperly specified and implemented.

The major goals of fault tolerant systems are increased weapon systems availability, mission survivability, and an affordable life cycle cost. Widespread acceptance of operational readiness objectives will probably be predicated on the demonstrated life cycle cost of those initial aircraft containing fault tolerant systems.

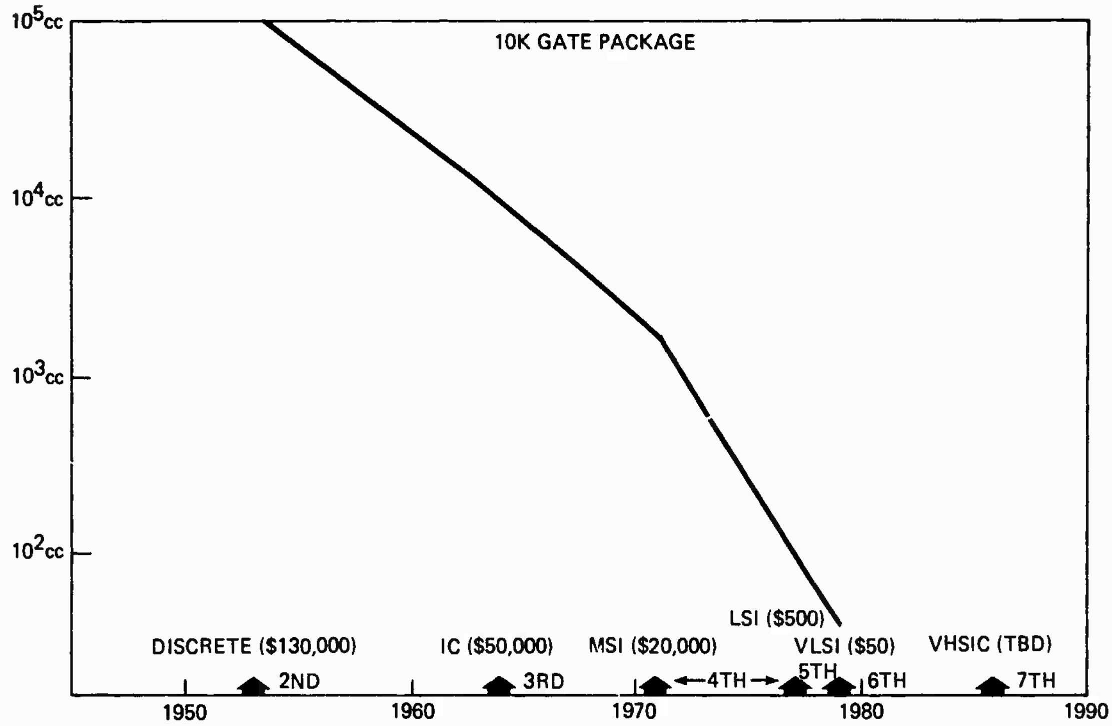
New technologies, such as Very Large Scale Integrated (VLSI) and Very High Speed Integrated Circuits (VHSIC), will have a major impact on tomorrow's operational effectiveness, provided the OR concepts are clearly defined and enforced. Processing elements, virtual memory techniques, and wideband buses are readily available for the next generation fighter. The design of weapon system computers capable of tolerating random hardware failures, has become a relatively mature technology at an affordable cost. However, full advantage must be taken of advances in computer technologies to integrate a fault tolerant design. Today, adequate methods exist to insure a high degree of availability and mission success through simple Built-In-Test (BIT) and auto-reconfigurable designs. This paper provides a managerial and technical roadmap for accomplishing the desired operational readiness goals in the next generation fighter. The contribution of the various attributes (including testability, avionic architecture, fault tolerant designs, BIT, standardization and operational readiness control) is provided.

II. TESTABILITY AND ITS APPLICATION

Current projections of computer technologies indicate a strong trend toward reduced avionic size, weight and cost, as well as greatly improved weapon system availability and supportability. The complexity of fighter avionics, however, will remain high as more and more mission functions are accommodated by the weapon system.

Projected trends in topography and packing densities of electronics work to the advantage and relative ease of partitioning circuitry for purposes of real-time testability. This is made possible by the integration of much higher-level functions on a single chip. There is no longer a need to worry about the failure modes of a single flip-flop, NAND gate or the like, now that the avionics can be reduced in weight and volume by an order of magnitude over that of the second generation electronics (See Figure 1). Ample built-in-test and redundancy can be incorporated at the system and equipment level to achieve the desired degree of operational as well as depot level testability. Function for function, the cost of VHSIC over that of a hybrid circuit (i.e., discrete and MSI), even with testability added, will be reduced significantly.

The design-for-testability (DFT) discipline is not black magic. Traditionally, however it has been an area often ignored by most operational design engineers. This lack of interest in DFT characteristics of the system (and subsystem) is the natural consequence of neither the market place nor supplier self-interest in placing DFT high on the list of design trade-off priorities. DFT is now emerging in a manner reminiscent of the Reliability/Maintainability (R/M) groundswell of the not too distant past. And as with R/M, the detailed effective implementation of DFT is primarily the function of the design engineering process. In a similar manner, the design engineering process requires inputs and oversights of DFT design requirements and validation by system engineers dedicated to the DFT discipline.



ⓝ– DESIGNATES ELECTRONIC CIRCUIT GENERATION

FIGURE 1. ELECTRONIC VOLUME & DENSITY CHANGES

Design-for-testability must accommodate all levels of test and repair. The degree or utilization of testability is largely determined by the maintenance level being considered. Built-In-Test (BIT) and performance monitoring is used at the Operational level and provides for a quick readiness status and fault isolation to major subsystems or units within the system. Testability at the Depot maintenance level relates to unit testing and the application of off-line Automatic Test Equipment (ATE) and special test devices.

Intermediate Level maintenance in support of future avionics will be relegated largely to a flight line removal and replacement function.

The Operational readiness concept for avionics must include provisions for:

1. Design-for-Testability (DFT)

2. Operational Test

3. Integrated Test & Maintenance (IT&M)

These OR features or attributes are better identified in Figure 2, which provides amplification of these specific OR categories of design. The concern is that an approach be implemented such that each of the interdependent elements of OR be integrated into the total weapon system design. To properly apply these disciplines, the system definition must provide for early identification of issues such as:

1. Availability/Reliability Requirements

2. Level-of-Repair

3. Testability Standards & Guidelines

4. Built-in-Test Features (Hardware & Software)

5. Functional Circuit Partitioning

6. Fault Isolation/Avoidance

7. Accessibility

8. Weight & Volume Considerations

9. Integrated Logistics Support

10. Life Cycle Cost Impact

Unfortunately, the tendency has been to treat each of the features (i.e., DFT, Operational Test and !T&M) of the OR weapon system attributes, independently of each other with little or no compatibility relative to system objectives. The criticality of this total integrated maintenance concept cannot be over-emphasized. The impact of designing the avionics with adequate BIT without considering the influence on the ATE design or onboard operational tests would neither be a sound nor a cost-effective strategy. Therefore, a model of the life cycle maintenance concept must be developed for the weapon system under consideration and it must be properly implemented and managed across all phases of design development and test.

DESIGN FOR TESTABILITY

- TESTABILITY STANDARDS
- BUILT-IN-TEST
- REDUNDANCY DESIGN
- CIRCUIT DESIGN AND PARTITIONING
- TEST POINTS/CONNECTORS
- ATE COMPATIBILITY

OPERATIONAL TEST

- INFLIGHT PERFORMANCE MONITORING SYSTEM
- SYSTEM DIAGNOSTICS
- FAILURE MODE REVERSIONARY PROCESSES
- FAULT CONTAINMENT
- AUTO-RECONFIGURATION AND RECOVERY

INTEGRATED TEST AND MAINTENANCE

- AUTOMATIC TEST SYSTEMS
- CALIBRATION/ALIGNMENT
- PREVENTIVE MAINTENANCE
- LOGISTICS SUPPORT

FIGURE 2. ACHIEVEMENT OF OPERATIONAL READINESS ENCOMPASSES:

Future weapon system designs must consider the total aircraft testability design as depicted functionally in Figure 3. A synergistic approach is necessary as a result of the highly integrated nature of advanced fighter technologies which include provisions for (1) solution-oriented tactical situations requiring instantaneous aircraft maneuvering (e.g., Terrain Following/Terrain Avoidance (TF/TA), (2) missile avoidance, (3) optimum coordinated attack profiles (air-to-air) and (4) overall energy management and thrust vectoring. Any one of the system elements must exhibit a degree of fault tolerance or graceful degradation (failsoft) which for any one failure will provide for a reasonable guarantee of mission success without major degradation or loss of aircraft.

General Bernard Schriever once said, "Many times we have found that the pacing factor in acquiring new weapons, support, and command and control system is not the technology, . . . it is management." Furthermore, weapon systems management often does not excel in all aspects of the aircraft technologies (i.e., Avionics, Flight Controls, Air-vehicle, and Propulsion) as well as the integration of the operational and test concepts. The tendency, therefore, is not to give equal consideration to these weapon system elements in a holistic fashion; consequently, the objectives of availability, operational performance, and life cycle cost have been compromised.

III. AVIONIC SYSTEM ARCHITECTURES

The advanced avionic system architectures of today utilize digital multiplex buses with interconnected multiprocessor subsystems dedicated to specific functions such as navigation, communication, weapon delivery, controls and displays, stores management, and target acquisition (Figure 4). More and more, software is assuming the traditional functional role previously allocated to the hardware design. Newly proposed avionic designs also emphasize integration of flight and fire control as well as propulsion control. Redundant avionic buses are utilized to provide a backup path for communications and navigation functions in the event the primary communication interface should fail.[1] There still exists a wide diversity of second order architectures and related allocation of functions to the various distributed processors. The processors embedded in the various subsystems are quite dissimilar in design, capability, language, timing and testability. Today's avionics incorporate these multiprocessor designs by specifying compliance with a common interface design, such as that defined in MIL-STD-1553B. This trend toward distributed architectures is aided by the many tri-service studies which have supported industry in defining this advanced technology. However, beyond system status checks and some consideration for manual system reconfiguration by the pilot, little has been accomplished in the way of automatic operational fault tolerance and reconfiguration of mission elements.

With the advent of the advanced avionics architectures comes the need for equally advanced tools to model the fault tolerant requirements and to establish affordable designs. Such models as the Markov and ARIES 81 models are serving to accomplish these goals. However, considerable sophistication must be added to existing CAD (Computer Aided Design) programs to allow for complementary automatic derivation of testability designs. Such models would also account for increase in component counts, reliability factors, physical budgets (weight, size, cooling), timing budgets and cost.

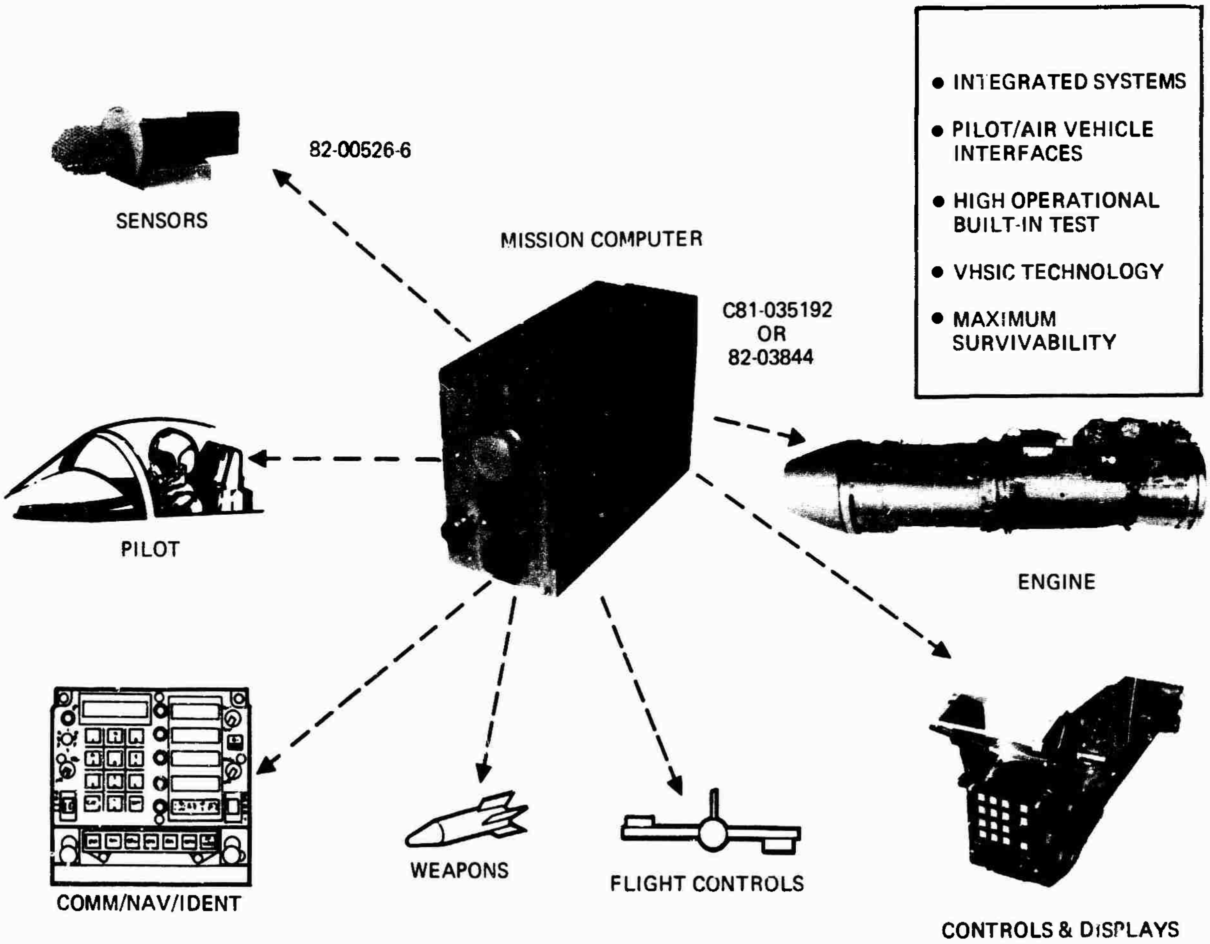
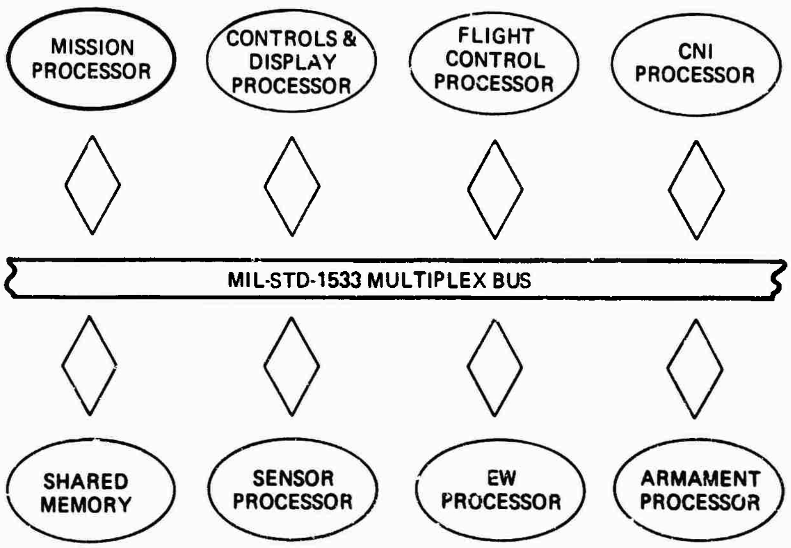


FIGURE 3. PILOT/AIR VEHICLE AND INTEGRATED AVIONICS SYSTEM

- COMMON/DISTRIBUTED/BUILDING BLOCK MULTIPROCESSOR
- WORKLOAD DISTRIBUTED MODULAR SOFTWARE
- DIRECT MULTIPROCESSOR SUBSYSTEM COMM.
- MULTIPLEXED DATA BUS
- STANDARD MODULAR SOFTWARE AND HARDWARE ELEMENTS
- SIGNIFICANT GROWTH FACTOR
- EASE OF REDUNDANCY AND SELF CONTAINED BIT
- SERIAL PROTOCOL BETWEEN MISSION PROCESSOR AND EACH OTHER PROCESSOR
- ANY PROCESSOR CAN SUPPORT FUNCTION OF MISSION PROCESSOR



CNI – COMMUNICATION, NAVIGATION, IDENTIFICATION
EW – ELECTRONIC WARFARE

FIGURE 4. DISTRIBUTED SYSTEM CHARACTERISTICS

IV. FAULT TOLERANT DESIGNS

Concepts being investigated for future use in fault tolerant design include continuous automatic reconfiguration, software implemented fault tolerance, and the use of functional redundancy in failure detection. The fault tolerant design for the future will strike a middle ground, borrowing ideas from all available technologies. For example, a certain degree of hardware redundancy together with reliance on software to provide functions such as fault isolation, diagnosis, and error detection and recovery will result in the most efficient means of attaining operational readiness. The use of functional redundancy, which is typically inherent in the system design, can vastly reduce the need for hardware redundancy. For example, the pitot-static/air data systems do not have to be duplicated to verify that correct indicated airspeed is being generated. Instead, an algorithm can be employed using the known values of aircraft mass, aircraft reference area, angle of attack, normal acceleration, and related constants to compute indicated airspeed for the purpose of verification. Primary factors which will influence the fault tolerant design and which must be considered in the acquisition of electronic systems and components are listed below:

1. System/Subsystem Architecture
2. Redundancy Management Criteria
3. Degraded Modes Operations
4. Fault Detection Techniques
    a. Comparison
    b. Redundancy Voting
    c. Periodic/Initiated Testing
    d. End-to-End/Diagnostics
    e. Event time-out
5. Fault Isolation and Containment
    a. Functional Partitioning
    b. Independent Operation
    c. Logical Modeling
6. Recovery (Coverage)
    a. Error Masking
    b. Error Detection and Correction
    c. Reconfiguration
    d. Retry
7. Tolerance Renewal
8. Environmental Constraints
9. Cost and Development Constraints

V. EXTENT OF BUILT-IN-TEST

The implementation of BIT in avionics is usually predicated on availability requirements which provide limits on the mean-corrective-maintenance-time at the Organizational Level. The fault isolation level of BIT is determined on the basis of functional modularity, accessibility, spares provisioning, repair skills of maintenance personnel and planned off-line test equipment.

A design for BIT optimization is favored over the more costly ATE approach. The mobility of military forces is such that complex ATE, with its associated adapters and support equipment, is less desirable than a comprehensive approach to operational BIT.

The cumulative effect of all elements impacting the BIT trade-off analysis must be weighted; they include such factors as:

1. Development and life cycle support costs
2. Impact on availability/reliability
3. Level of isolation afforded in terms of ambiguity ratios
4. Impact on weight, size and access

5. Impact on environmental conditions (e.g., cooling, EMI, shock)

6. Added power requirements

Further, BIT must be traded off with the established testability philosophy and the selected ATE. When ATE provisions are sufficient for total off-line maintenance support, extensive BIT may not be necessary. The U.S. military would prefer to remove a Shop Replaceable Unit (SRU), rather than an electronic unit or subsystem at the Operational level. Thus, the avionics design concept and maintenance philosophy must allow for unambiguous isolation to the card level. At the same time, the weapon system design concept must allow practical flight line access to the failed card. The Operational test software must be compatibly interleaved with the operational flight program in order to support this philosophy.

Accomplishing this BIT approach is tantamount to designed the original avionics, and Figure 5 provides a representation of the hidden areas for consideration. A master plan with the appropriate maintenance philosophy and design-for-testability specifications must be established early in the planning phases. Standardization, packaging, environmental constraints, acceptance criteria and the like must all be firmly established and disseminated to the affected design organizations.

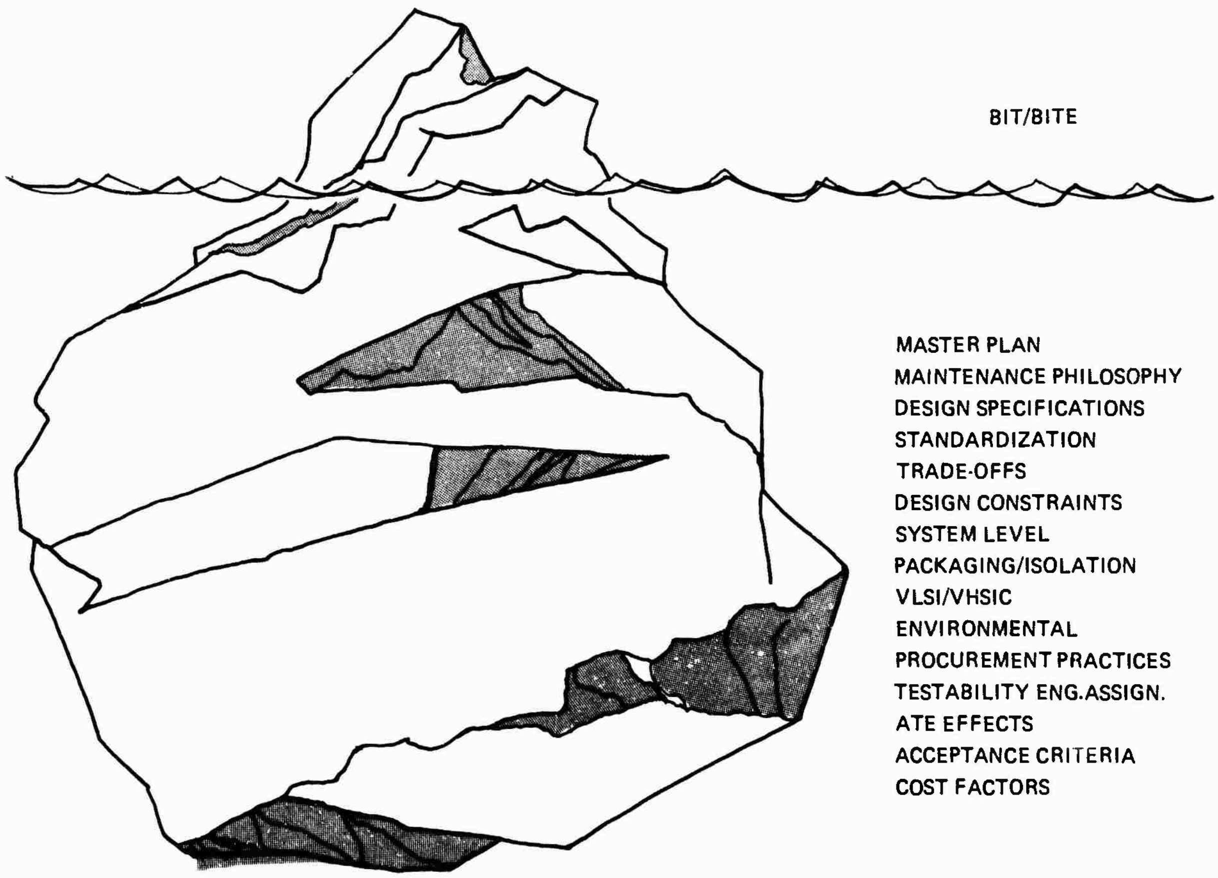


FIGURE 5. THE BIT ICEBERG

The Organizational Level tests must be properly fused with the execution of the operational functions such that minimum vigilance and manual reconfiguration is required of the pilot. Detection, isolation and the self-healing processes will generally be transparent to the pilot with alerts and cues provided after the fact. Figure 6 provides an architecture test philosophy which illustrates this concept. The pilot will have a choice of accepting the systems failure mode recovery or of selecting an alternate, if one exists. Aircraft safety and mission success will continue to be the motivating factors in selecting the automatic or manual modes.

Specific approaches to avionic BIT designs might include on-chip testability with monitor circuits added for failure detection and circuit feedback, summing networks and provision for interface status, as shown in the example of Figure 7. A nondestruct memory would permit immediate post-flight determination of failure status without the necessity of rerunning extensive aircraft ground test; thus, providing for improved weapon system turnaround time. Furthermore, inflight recording of fault data would allow analysis of transient type conditiona that may not be apparent during post-flight maintenance.

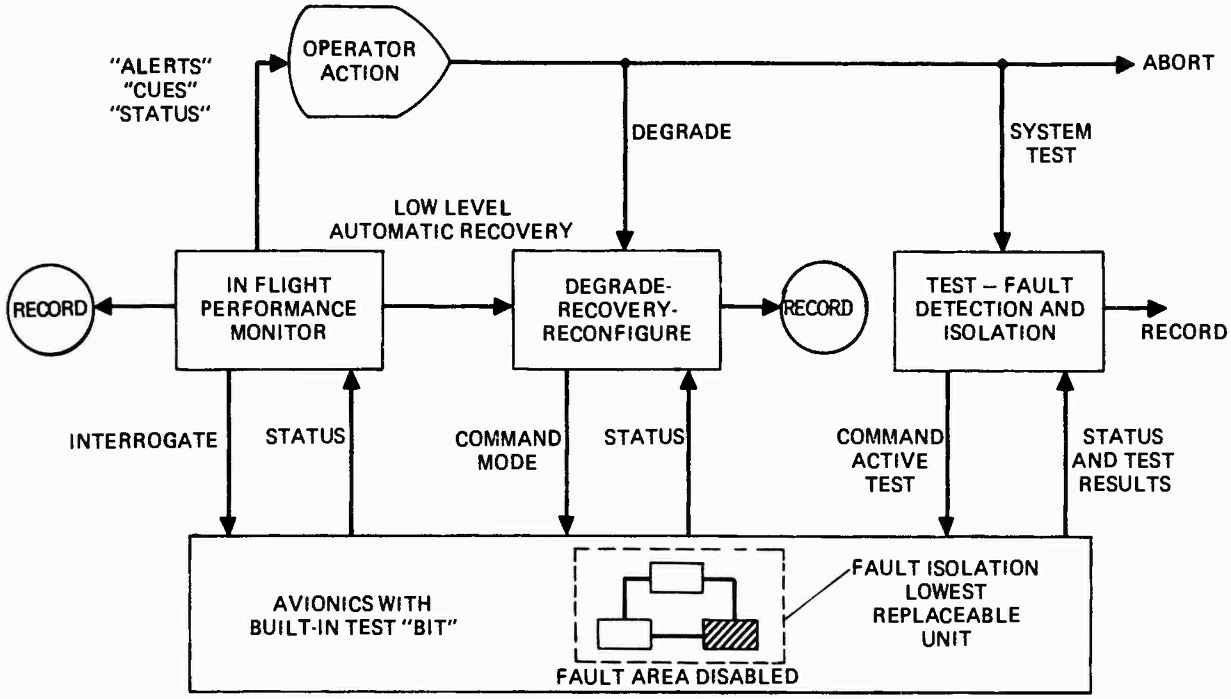


FIGURE 6. ORGANIZATIONAL LEVEL TESTING

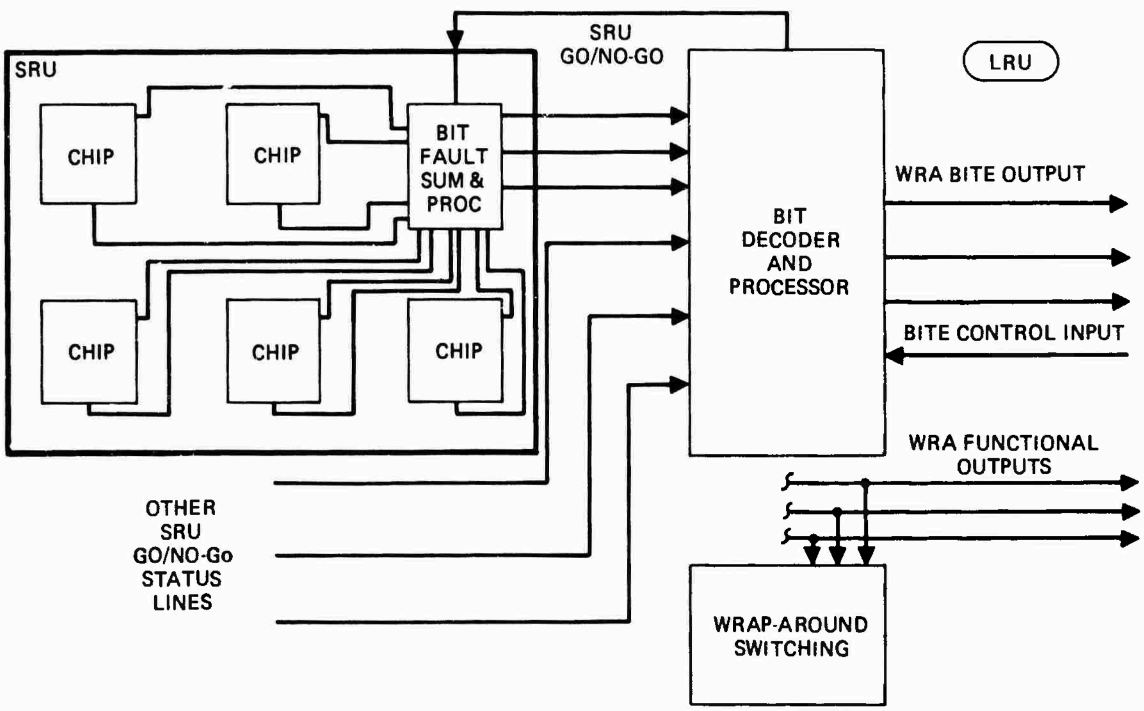


FIGURE 7. DYNAMIC PERFORMANCE MONITOR SRU/CHIP LEVEL

In the considerstion of sdvsnced svionic designs which allow for highly fault-tolcrsnt architectures, s standsrd VHSIC processor msy be utilized in s building block fashion to permit sutomatic reconfiguration of s failed microprocessor component. This csn be sccomplished by allowing the stscked processors to perform in s task queue priority scheme, whereby the processor next in line can be sssigned to perform the next function in line. Therefore, if any processor should fail in the queue, the next processor in line would assume the functional processing role. This would provide s completely transparent fault-tolerant system with no apparent reduction in mission performance. The determination and partitioning of the quantitative number of operational and spare processors required would be established by the criticality of specific mission modes and acceptable reliability levels. The memory of the respective processor elements could also be treated as nondedicated elements and applied to the same redundancy management scheme. Standard processing elements would be moved as far out into the subsystem functions as possible to achieve as high a commonality factor as possible. Only those elements or functions of the subsystem requiring special circuit/software design need be unique. Figure 8 provides just such an architecture which could easily accommodate the next generation fighter multi-mission functions.

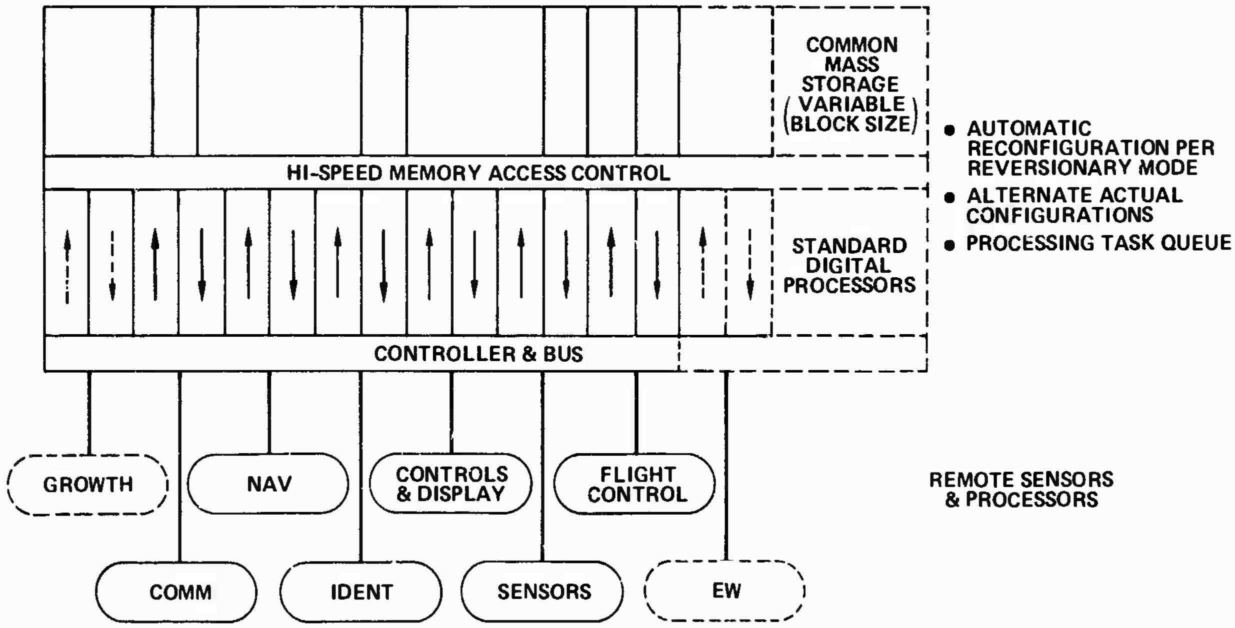


FIGURE 8. ADVANCED ARCHITECTURE (FAULT TOLERANT)

VI. STANDARD BUILDING BLOCKS

At the outset of a new system design, testability standards and guidelines should be established to influence the end product toward realizing the desirable effect on availability and maintainability. However, many new systems are partial derivatives of existing designs or utilize 'off-the-shelf' electronics and are highly influenced by the test philosophy underlying that predecessor design. Such mixed systems create complex integration problems, and testability designs are generally compromised. Furthermore, test equipment compatibility is seriously affected, and the need for added test capability and interfacing devices is considerably expanded.

To reduce the diversity of avionic designs, the author proposes that a standard building block approach be adhered to by all subcontractors providing new electronic systems, subsystems and component designs. Equipment specifications must stipulate the design requirements for both functional and testability requirements for the unit under test (UUT).

The standards employed currently at Northrop include, as a minimum, the following:

1. MIL-STD-1750A Computer Architecture
2. MIL-STD-1589B JOVIAL J73B Language
3. MIL-STD-1553B Multiplex Bus Interface
4. MIL-STD-52779 Software Quality Control
5. AFR 800-14 Acquisition Management
6. MIL-STD-483 Software Configuration Management Practices
7. MIL-STD-490 Specification Practices

A complementary set of company standards such as a Software Development and Management Plan and a System Engineering Management Plan (SEMP) also serve to provide engineering design direction and control.

A system design will make use of these standards in a building block fashion, such that functions can be easily added or deleted either from a software, hardware, or interface design standpoint.

The areas of concern relating to the standard building block approach must, however, also include consideration of the following factors:

1. Maturity of the building blocks
2. Universal application to systems and subsystems
3. Common interface boundaries (I/O conversions, protocol, software, physical and electrical compatibility, testability, etc.)
4. Distribution of functional work loads
5. Throughput and timing relationships
6. Timeliness and cost for implementation of standards
7. Configuration control
8. Obsolescence

The application of VHSIC designs to future avionics (e.g., Radar, CNI, Fire Control) and related fault-tolerant designs will also play a major role in standards of the future.

VII. AVIONICS OPERATIONAL READINESS CONTROL

A system management process to provide for timely integration of Operational Readiness concepts into the system design is important to successful implementation and deployment of the weapon system. The key milestones and events of the testability design process are influenced by the same events that influence the operational design. Therefore, management controls which include development standards, design reviews, documentation control, baseline management, hardware and software configuration management and the like must be imposed equally on the Operational Readiness design requirements.

Figure 9 provides a program development flow which identifies the critical control elements, the most critical of which are the mission/readiness requirements and the testability design standards/guidelines. These requirements must be established and approved early in the definition phase and monitored throughout the development, test and verification phases.

Critical design reviews will include an in-depth testability design compliance verification which will include:

1. Circuit Design Review (Schematic Level)
2. Equipment Test Verification
3. Operational System Test Compatibility
4. Maintenance Support Review
5. Ground Support Test Compatibility

All of these reviews will be conducted in accordance with established standards and guidelines. The acceptance criteria will have to be specified at each level of evaluation to ensure total system compliance from the bottom up. These acceptance criteria must be weighted on the basis of their impact on the weapon system (availability, mission reliability, and testability, as well as life-cycle cost) or objectives. Historically, this has not been an easy task unless top-down systems management has been strictly imposed. To do this, the weapon systems manager must cross all lines of discipline and enforce strict compliance and proper performance tracking techniques. Essential to the success of this top-down management approach is a timely integration of the OR requirements with those of the operational development events.

VIII. CONCLUSION

(OK)

Achievement of Operational Readiness requires an interaction with the functional design and must be built into the system and controlled from the top down. The payoff is obtained in terms of enhanced mission success, improved availability/reliability, and reductions in maintenance and life cycle costs.

Testability in microprocessors must start at the level of the chip design. Many techniques such as nodal summing points, redundancy switching and dynamic macrotest software are known today and can be easily incorporated at the outset of the processor design, by ~~utilizing~~ using automated design aids.

Cost reduction goals can be realized with the elimination of the intermediate level test system and a reduction in the cost of the depot/factory equipment. Life cycle costs can be drastically lowered by the reduction in maintenance training and support costs.

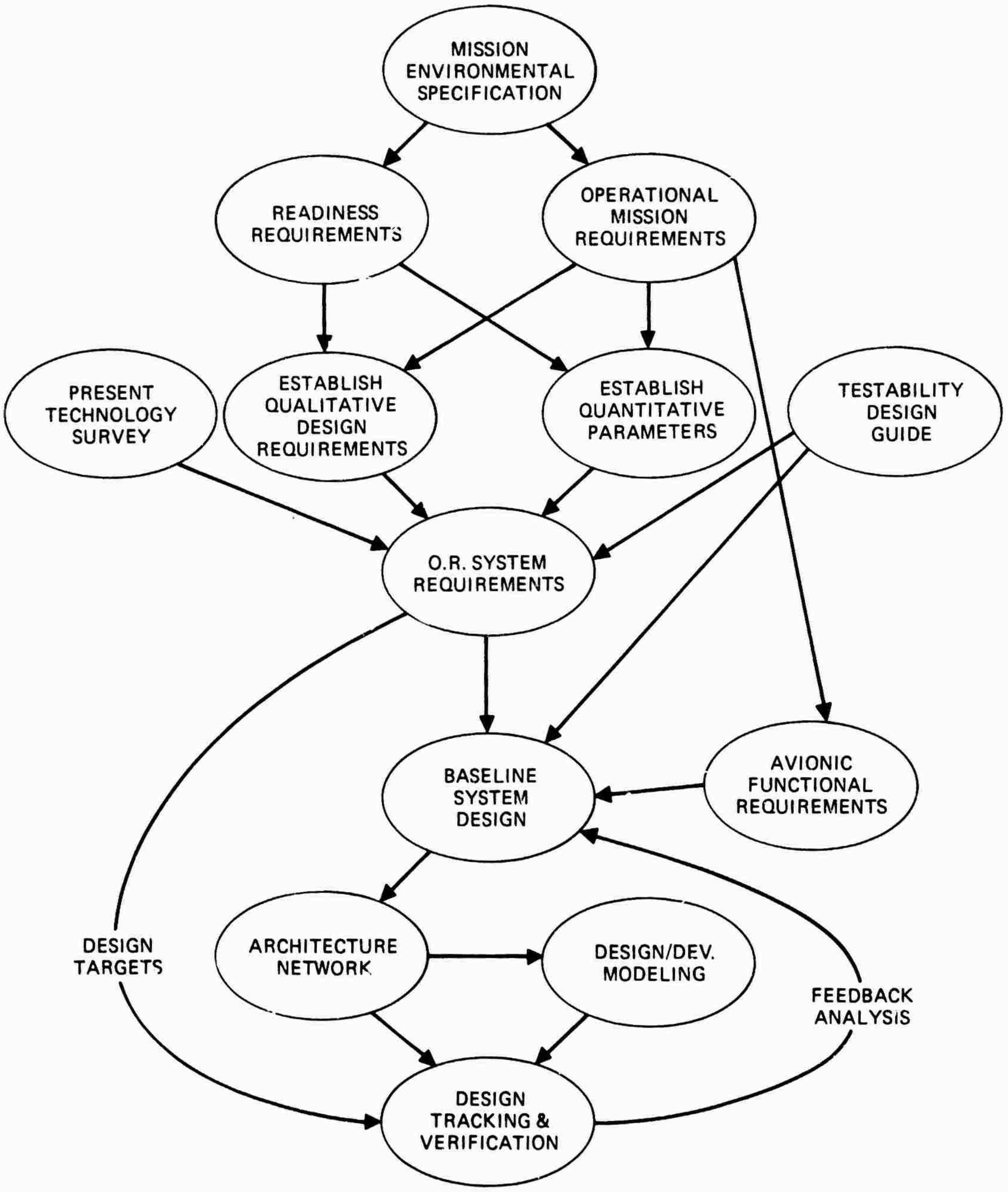


FIGURE 9. O.R. DEFINITION AND CONTROL APPROACH

Operational Readiness improvements will be made possible by several new advances in technology. The new electronic components will permit the inclusion of advanced testability concepts into airborne avionics. Advances in software and design of new distributed-system architectures will provide for a universal set of testing standards. Achievement of ~~the Operational Readiness~~ concepts will be obtained through integration and control of each of its related elements, thus providing a marked increase in weapon systems effectiveness.

OR The deployment of weapon systems which have been designed to comply with operational readiness requirements hold ~~a~~ significant promise of improved availability while reducing life cycle cost and manpower requirements. Comprehensive management and technical training efforts are, however, required to take advantage of the potential. Guidelines and standards, such as those proposed under the tri-service Joint Logistics Command (JLC) program, will serve to accomplish these operational and support goals.

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DISCUSSION

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A high degree of standardization is now possible through the use of the MIL Bus, but will a standard interface really be plastic enough to cope with the fault tolerance requirements of the various terminals of the bus? Perhaps one should really talk of modularized interface elements as opposed to standardized units. The required interface could be constricted by defining a certain mix of the modules with the appropriate interleaving software. In this case then perhaps these modules could form a library of standardized elements.

Author's Reply

A standard interface, be it a single VHSIC or several elements, can be plastic enough to satisfy the fault tolerance requirements if properly designed up front to do so. Operational monitoring and wrap-around testing augmented with interleaving operational/test software. The goal is not to stop with this interface but also standardize on the subsystem processors and programming language thus reducing the major logistic costs.

AD P002842

AVIONICS CONCEPT EVALUATION AT THE FORCE LEVEL

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SUMMARY

The development of new avionics systems should be guided and supported bv force level analysis. Evaluation at the force level is necessary in order to assure that a concept, as it is conceived and developed, will indeed provide a significant increase in capability when the resulting weapon system is used in an operational environment.

The Weapons and Tactics Analysis Center (WEPTAC) at the Naval Weapons Center is a war-gaming facility for doing force level analysis. It is used to evaluate weapon systems and tactics as they would be employed in realistic scenarios involving opposing forces. It provides a valuable tool, therefore, for the evaluation of avionics concepts.

This paper discusses the importance of force level analysis in avionics system development, describes the WEPTAC facility, and gives an example of the use of WEPTAC to evaluate an avionics concept.

INTRODUCTION

Force level analysis is the evaluation of weapon systems in the context of important scenarios that involve many interacting friendly and enemy weapon systems, all employed with realistic tactics. In other words, it is evaluation of weapon systems in the complexity of operational environments.

Force level analysis is important from the start to the finish of the development of an avionics concept. A new concept should be introduced in response to operational needs, which may well be discovered by force level analysis. During the process of concept definition and refinement, force level analysis is needed to evaluate the proposed system's contribution to weapon system effectiveness in the operational environment. Based on the results of these evaluations, the concept may be redefined, radically changed, or dropped.

It is important that today's scarce funds for new concept design and development, and also for technology base research, be allocated only to projects that may appreciably improve overall weapon system capability in future scenarios. Force level analysis of new concepts that exploit promising new technologies can provide the planner an important tool for evaluating both the concepts and the technologies.

The capability to do force level analysis is increasing with the rapid advances in computer hardware and software. Given its importance, force level analysis should be done formally as part of the synthesis of new avionics suites.

The Avionics Division at the Naval Weapons Center is developing a method for avionics suite synthesis. The method consists of an ordered set of computer models that are linked together to predict the performance, and evaluate the effectiveness, of a new avionics concept in the successive stages of synthesis from components to weapon system. The purpose of the method is to provide a systematic, flexible evaluation process that will be used to guide the development of conceptual avionics suites. The capability to do concept evaluation at the very early stages of concept development will also help generate a technology base that is driven by requirements.

Figure 1 shows how force level analysis fits into an overall method for avionics suite synthesis. An operational need, perhaps revealed by force level analysis, results in a new avionics concept. As a result of modeling at the component and weapon system levels, values for performance parameters—such as navigation accuracy, probability of detection, probability of kill, probability of survival, and reliability—are obtained. Costs are also modeled and judgments are made about the technological risks associated with the new concept. The performance parameters are inputs into a force level analysis that evaluates operational effectiveness in terms such as the numbers of targets killed and the numbers of friendly aircraft lost. The results of the force level analysis and the cost and risk information are then combined in an overall evaluation of the avionics concept as it would be synthesized into a weapon system, and the advantages and disadvantages of the concept are summarized, leading to recommendations for, or against, development.

The process as pictured in Figure 1 is simplified. In a typical case, there will be many loops back to the beginning to redefine the concept.

WEPTAC

The synthesis method being developed at the Naval Weapons Center uses the WEPTAC war-gaming facility as the tool for force level analysis. Each wargame involves three teams of players: a friendly "blue" team, an enemy "red" team, and an umpire. At present, there can be a total of 8 players divided among the teams. A typical arrangement of the players in the facility is shown in Figure 2.

The players control up to 200 units, a unit being a platform or missile. Each unit can be fitted with up to 30 weapon and sensor types. The central computer that provides this capability is a 16-bit, Hewlett-Packard system 1000 minicomputer. Plans for the near future include a 32-bit minicomputer and the capability for 12 players controlling up to 400 units.

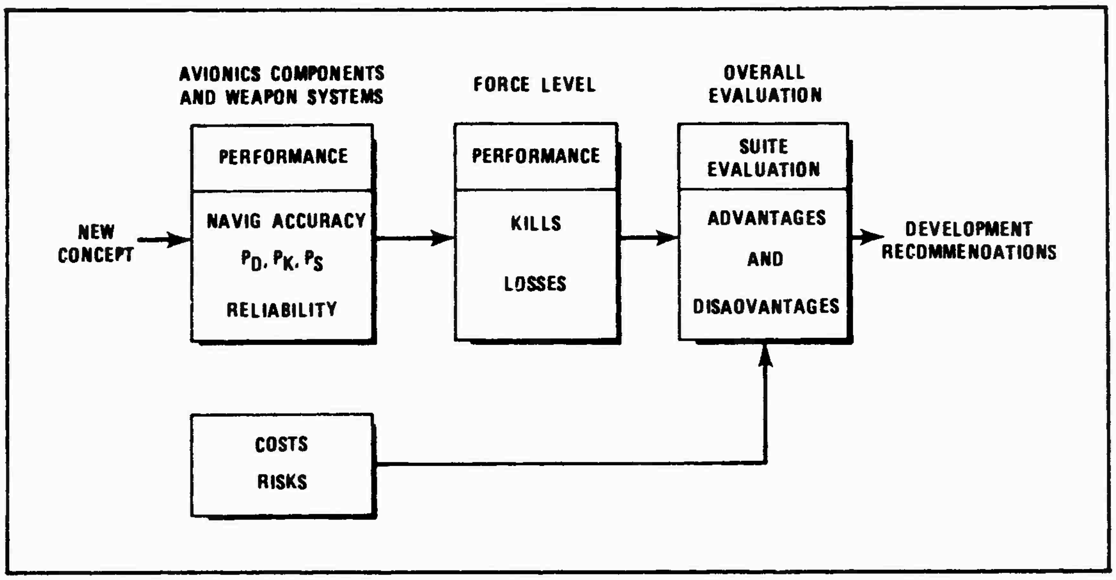

FIGURE 1. Force Level Analysis and Avionics Suite Synthesis

Each player has available several pieces of equipment (Figure 3). There is a terminal on which an operator, assigned to the player, communicates his decisions to the computer. There is a graphics display screen on which is mapped the location and course of all units that the player controls or has information about. There is a console that is used to display, in tabular form, the status of any platform under the player's control and the status of its sensors and weapons; it also displays the information the sensors have obtained about enemy units. Also, there is a printer that produces a record of all events in the game that the player would, in real life, know about. Finally, for later reference and analysis, at any time in the game a player can ask the umpire to make a hard copy of the scene displayed on the umpire's graphics display, which shows the locations of all the units.

The use of WEPTAC starts with the definition of an appropriate scenario. This can be either a war-at-sea or a force projection scenario, although the WEPTAC projection capability is limited since terrain is not at present modeled. Given the initial friendly and enemy platform positions, the players make decisions to maneuver their platforms, manage their sensors, and fire their weapons.

As the war game proceeds, the results of the various interactions are calculated by the computer using algorithms that model

- Detection by radar, sonar, and other sensors
- Noise and deception jamming
- Weapon guidance
- Identification and classification of targets
- Communications between platforms
- Logistics
- Refueling
- Target damage.

Platform courses, speeds, and intercepts are calculated in three-dimensional geometry.

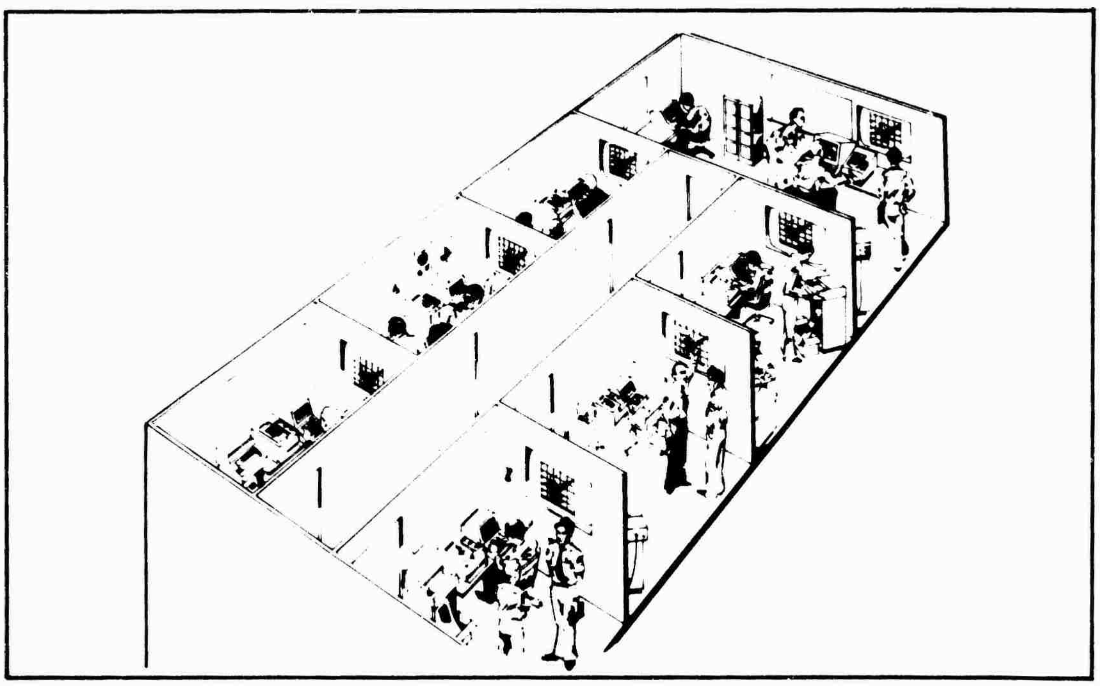

FIGURE 2. Layout of WEPTAC Player Stations.

At the end of the game, event summaries are printed out in various formats by the computer, providing much useful data in addition to the force level measures of effectiveness such as target damage and number of survivors. Less tangible products are the insights that arise from modeling the use of a new weapon system concept in an operational setting. These are as important as the quantitative results.

WEPTAC realistically models the process of operators making quick decisions based on partial information. It is especially appropriate, therefore, for the evaluation of avionics capabilities involving information such as detection, jamming, communications, and identification.

Runs on WEPTAC can be played either in a war-game mode, with the players making interactive decisions as described above, or in a noninteractive mode. In a noninteractive mode, tactics are decided on beforehand, engagements are treated automatically, and many runs are made to generate statistics.

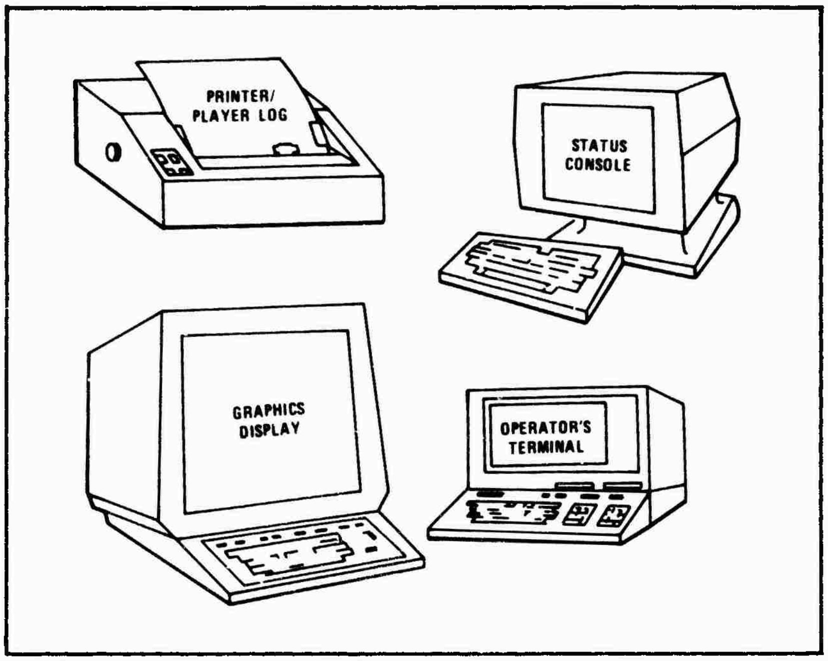

FIGURE 3. Player Equipment.

EXAMPLE OF CONCEPT EVALUATION USING WEPTAC

Listed below are some typical questions related to avionics that could be studied using WEPTAC or some other force level analysis model.

- How much additional detection range would be useful given today's weapon systems?
- For a new sensor type, what is acceptable resolution and accuracy?
- How do tactics affect the requirement for jam-resistant communications?
- Should ship identification avionics be in the weapon, the delivery aircraft, or another aircraft?
- How useful would it be to extend the range at which high-value ships can be identified?

The following paragraphs describe how WEPTAC might be used to address the last question, and thereby evaluate a ship-identification concept.

Consider a conceptual ship identification system proposed for attack aircraft. It will provide a 90% probability of detection of a high-value ship at a distance of X nautical miles, X being larger than the identification range obtainable currently and matching the range of a new air-to-surface missile. The time required to do the identification is T seconds. WEPTAC is to be used to evaluate the effectiveness of this new concept in killing the high-value ships in an enemy task force.

First one needs to choose an appropriate scenario. In this example the enemy task force has nine ships, three of these being of high-value as shown in Figure 4. The initial information state for the attacking aircraft needs to be specified. In this example, as the attack aircraft approach the task force outside of their detection range, it is assumed that they know only that the target is a nine-ship force.

Initial tactics for the attacking aircraft need to be decided on. A coordinated two-pronged attack is shown in Figure 4, each prong containing four aircraft that launch the standoff air-to-surface missiles.

Figure 5 shows profiles of the missile launching tactics used in the baseline case and in the case where the new ship identification system is used. In both cases, the attack aircraft fly in under the task force's radar horizon and pop up to detect it and launch their missiles. Using the new avionics system, the attacking aircraft can also identify the high-value ships in the task force. However, the time required up in the enemy surface-to-air missile envelope is longer in order to accomplish the identification.

Operational decisions made by the players are important. For example, a factor that would influence the effectiveness of this new concept would be the time at which an attack aircraft fires its missiles. How many ships will have been detected, and how many identified, before missile launch? Figure 6 shows a case in which missiles are launched after five ships have been seen, one of which has been identified as high-value.

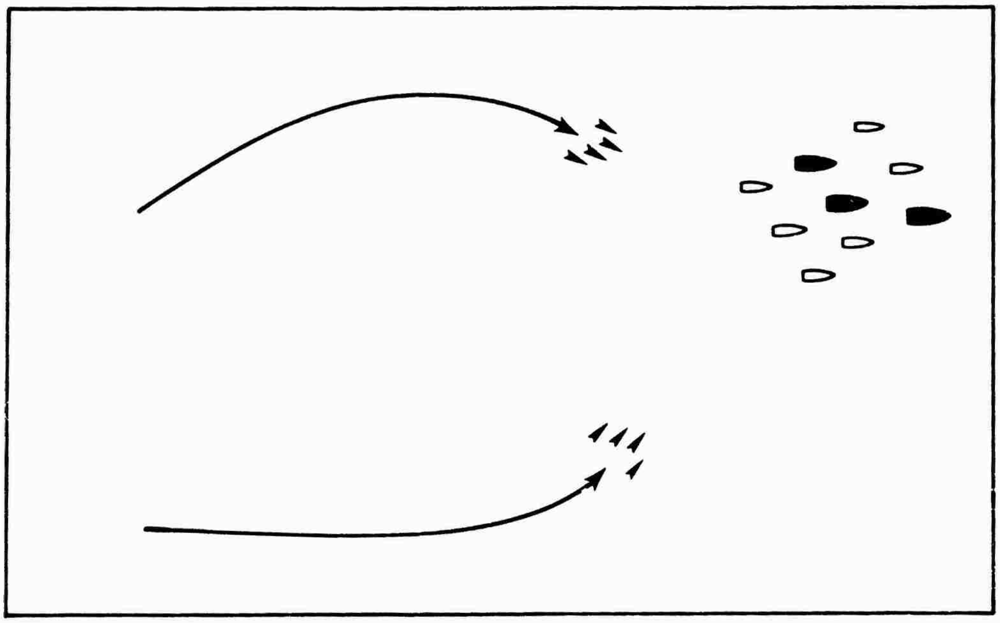

FIGURE 4. Scenario for Evaluation of Ship-Identification Avionics.

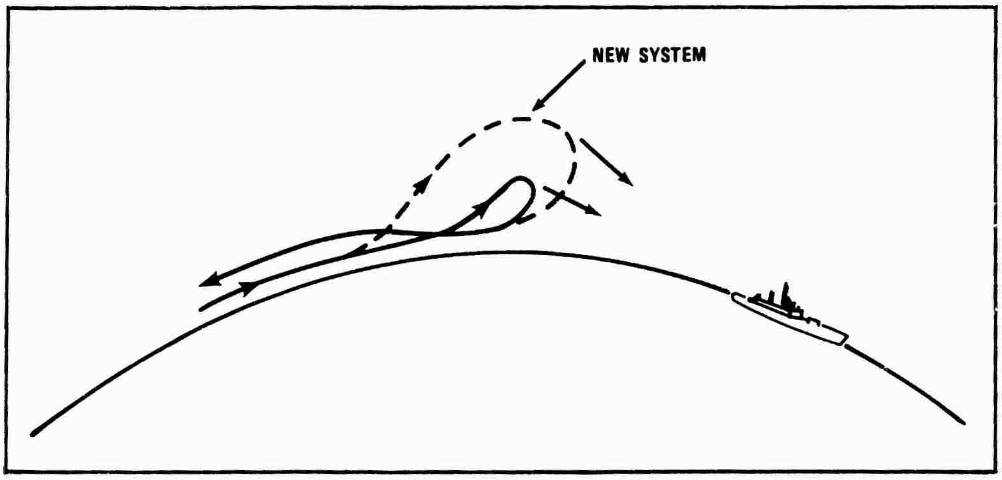

FIGURE 5. Missile Delivery.

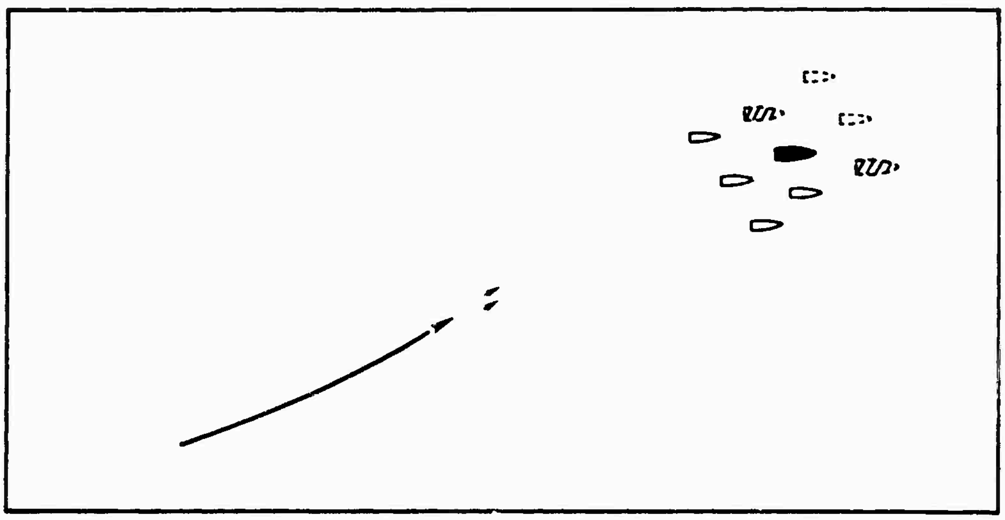

FIGURE 6. Information State at Missile Launch.

An evaluation of this ship-identification concept at WEPTAC would involve several interactive runs. (It would be best if attack pilots were used as the players controlling the attack aircraft and making the decisions on tactics and missile launch times.) It might be that after the interactive runs, noninteractive runs would be made starting from missile launch in order to get good statistics on ship kills and aircraft losses.

One kind of data one could obtain from a WEPTAC evaluation of the new concept is shown in Figure 7. (The numbers shown are hypothetical and not from any actual WEPTAC runs.) The shaded bars show the results, averaged over the appropriate runs, of the task force attack when the aircraft have the new identification capability. The clear bars are for the baseline case. Kills of high-value and other ships are shown, as well as losses for the attacking aircraft.

If the data in Figure 7 were real data, the new avionics would indeed be effective in increasing the number of high-value ship kills. This is at some cost, however. The number of aircraft losses increases. One would probably look at these results and conclude that it was a good trade: an average gain of about one and a half high-value ships for an average loss of about two aircraft.

A closer look at the data from the WEPTAC games might reveal more information. By examining the records of the games, it might become clear that there was considerable variation, depending on the player, in the length of time spent up in the enemy surface-to-air missile (SAM) envelope detecting and identifying the task force ships. One could then make several runs, with various pop-up time intervals, exploring the trade-off between gaining information and exposure to enemy SAMs.

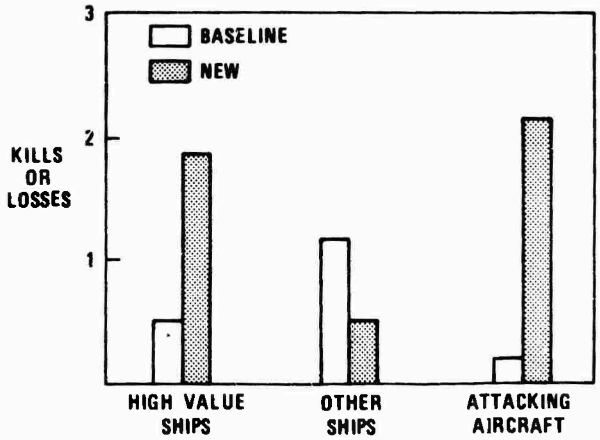

FIGURE 7. Effects of New Avionics.

Figure 8 compares the results for a particular pop-up time, T_p, and one that is three times as long. The clear bars are for T_p, the shaded bars for $3T_p$. The baseline results, without the new capability, are shown as dashed lines.

If the results are as shown, staying up in the ships' SAM envelope for the smaller length of time still yields very nearly as many high-value ship kills as are obtained from staying up for the longer time to gain more information. And now, the aircraft losses are way down. If the new avionics were installed in attack aircraft, it would be important to have some doctrine for the total amount of time spent on the identification process.

The evaluation of the new avionics would then need to look at different tactics, different management of the enemy task force assets, and different task force composition and orientation. It would also be useful to vary the time, T, required for identification to see how important it is to try to make it smaller.

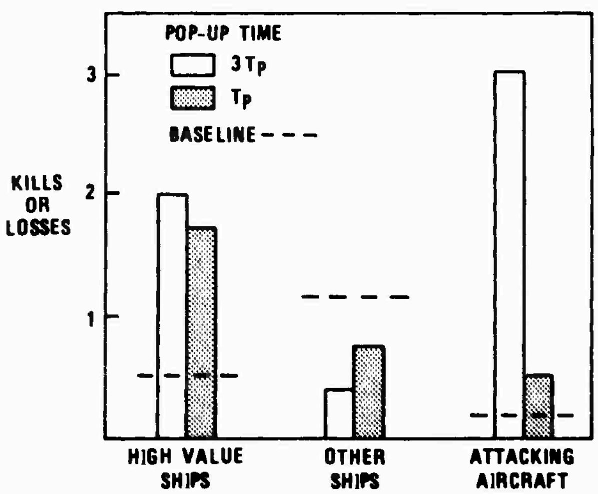

FIGURE 8. Effects of Pop-Up Time.

From all this, one would obtain much data and many insights. It has been mentioned before that the insights derived from force level analysis are frequently as important as the quantitative data. Insights (again hypothetical) that might be derived in the evaluation of new ship-identification avionics are:

- The new capability would be used only if detection-to-identification time could be held below some maximum value.
- Attack pilots tend to fire when the first high-value ship is identified
- The improvement in high-value ship kills is not very dependent on enemy resource management decisions.

WEPTAC would thus produce data and insights that could be used to evaluate the new ship-identification avionics concept. It might really be good, or need some additional work. It might turn out to be useful only in special situations. Or it might clearly not be worth developing.

CONCLUSION

Force level analysis plays an important role in avionics design. It can be used to evaluate existing systems, develop avionics requirements, evaluate conceptual systems, direct research and development efforts to systems that can produce large increases in capability, and focus technology base development towards those areas that are most likely to increase actual operational capability.

There are several advantages to using a facility like WEPTAC to do force level analysis of avionics concepts. It offers a ready-made way to integrate many systems and functions. It provides an excellent forum for operators and analysts to exchange ideas, experience, and data. Seeing the results on a graphics display in real time is a very effective way of absorbing information about a concept's effectiveness. Finally, it provides the closest approximation available to an actual operational environment for the evaluation of conceptual weapon systems.

DISCUSSION

M.Burford, UK

The definition of the attributes of the baseline element in a comparative evaluation of changes in system design at force level would appear to play a dominant role. In the past, the driving motivation has always been to produce a system superior in performance to that held by the "enemy" or presumed "enemy". However, in future the motivation may be to replace an already superior system on an inservice grounds. How are the attributes of the baseline selected or identified and are there any plans to capture the results from a study in a form such as a data base so that the impact of the analysis may provide inputs in future designs?

Author's Reply

The baseline is selected by the user of WEPTAC or some other force level analysis model, so that it is appropriate for the specific decisions that his avionics is intended to illuminate. The results of each analysis, as well as a summary of the scenario and the important assumptions, are kept for future reference.

A FUTURE SYSTEM DESIGN TECHNIQUE BASED ON FUNCTIONAL DECOMPOSITION, SUPPORTED BY QUANTIFIABLE DESIGN AIMS, AND GUIDELINES FOR MINIMUM MAINTENANCE COSTS

by

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SUMMARY

The increasing cost and complexity of modern fast-jet aircraft, coupled with the long development period which takes place while technology is changing rapidly, make it necessary to consider a new approach to system design. Such an approach should be based on a structured top-down procedure, in which the rather general requirement can be changed into a detailed documented design in a controlled manner.

One important aspect of design is cost, and in particular cost-effectiveness and life-cycle cost. At least some of the design aims can be based on cost-effectiveness reasoning, and it is necessary to have an appreciation of the background to this. Reliability-dependent maintenance costs can amount to much more than the original purchase price, and hence it is essential to be aware of the possible cost-drivers, and include maintenance aspects in the design approach from the beginning.

This paper describes some of the work carried out at RAE on these aspects.

1 INTRODUCTION

The interval between feasibility studies and the in-service date for offensive-support aircraft is several years. Increasingly rapid advances in electronics require that a new approach must be adopted in future system design to avoid aircraft entering service with unnecessarily out of date technology. It is therefore necessary to start the feasibility studies by undertaking a 'functional design', which is kept as abstract as possible, and to delay producing a detailed 'technical implementation' to as late as reasonable in the project. The functional approach has to achieve a solution which satisfies agreed design aims for safety and for mission failure. In addition, life-cycle costs (LCC) must be minimised, and a successful attempt to do this can only be mounted in the early stages of design.

The paper describes work concerned with this approach, and covers three particular areas as follows:

(a) the necessity for, and the approach to, 'functional design',

(b) proposals for design requirements for safety and for mission failure, and practical difficulties in applying such aims,

(c) the contribution of reliability-dependent maintenance costs to LCCs. The results of a quantitative analysis of the various facets of the maintenance burden with current avionics are presented, and suggestions made for improvements with future designs.

2 SYSTEM ARCHITECTURE

For any avionic system four architectures can be defined which represent the system in a top-down, structured manner. They are:

(a) The Functional Architecture; which defines the functions which the system must perform and the ways in which they inter-relate. Supporting information outlining safety criteria, mission failure rates and guidelines for minimum life-cycle cost also forms part of this architecture. The Functional Architecture thus totally represents the requirement.

(b) The Conceptual Architecture; which represents the first level at which an attempt to mechanise the system is made. This mechanisation is not performed in terms of hardware and software but, rather in terms of more abstract concepts such as the data flows and algorithms required to support the system functions.

(c) The Hardware and Software architectures; which describe the actual hardware and software structures used to implement the Conceptual Architecture. Naturally, the implementation will be determined not only by the functions to be performed but also by the guidelines for safety etc contained in the Functional Architecture.

The relationship between these architectures is shown in Fig 1 which also represents the ideal order in which they should be defined ie the Functional Architecture should be defined first. This is not always possible because, in some projects, the hardware architecture is pre-defined. Nevertheless, the need for the four architectures still exists to ensure that a complete record of the project is available from requirement to implementation. It is only by producing these architectures that subsequent modifications at any level caused, say, by a re-assessment of the threat or a major advance in hardware or software techniques, can be made in a top-down, structured manner and documented in a consistent and unambiguous way.

The remainder of this paper describes the work being performed at RAE Farnborough towards determining methods of producing Functional Architectures for future projects. Chapter 3 will concentrate on the functional description aspects of the task while Chapter 4 will describe the work that has been performed on design aims for safety etc. Chapter 5 will discuss design procedures for minimum life-cycle cost. Naturally, for a particular project, the rather general work on design aims and life-cycle cost would form a background against which techniques pertinent to the aircraft and its operational scenario would be determined. These, and the functions required to fulfill the aircraft's mission would then form the Functional Architecture for that project.

3 FUNCTIONAL DESIGN

3.1 The need for Functional Design

To date, avionic system design has been largely driven by hardware implementation considerations although, in recent years, software implementation problems have increased in importance. Possible reasons for this hardware dominance are:

(a) Most avionic system engineers are trained in hardware related disciplines.

(b) Most major innovations occur as a result of hardware related activities or, at least, the reporting of innovation gives that impression.

(c) Traditionally, aircraft functions have been identified in terms of particular pieces of hardware, often on a one to one basis.

(d) The belief that software is flexible has allowed avionic system engineers to concentrate heavily on the hardware design of systems.

This hardware driven approach to avionic system design is becoming increasingly difficult to apply for a number of reasons. Amongst these are:

(i) Advances in integrated circuit technology coupled with the advent of bussed data transmission techniques are leading to avionic systems in which individual pieces of hardware are no longer associated with particular functions. Not only may a function obtain data from and distribute its processing among a number of hardware items but also the way in which the processing is distributed may vary as a result of aircraft phase of flight and other, mission related, activities.

(ii) The long gestation period of modern military aircraft leads to a situation in which many technical advances will have taken place before the aircraft enters service. Such advances cannot usually be capitalised upon because of the current practice of defining hardware as early as possible in the procurement cycle.

(iii) The leaving of software definition until late in the project leads to the need for software retrofits which often follow the aircraft into service and thus lead to high software life-cycle cost.

It follows that, in order to alleviate problems caused by the hardware approach to system design the system requirement must be divorced, as far as possible, from the implementation of the system. It is therefore imperative that early system design be performed in functional terms only and that these functions should be as abstract as possible to distance themselves from implementation considerations. The technique used for documenting the functions should also allow consideration of the wider scenario to be made so that all the factors that determine the avionic system requirement can be taken fully into account. Thus, the functional design should commence at a level at which logistic support, strategic operational considerations and similar pertinent factors are under discussion. In fact, the design should evolve throughout the Air Staff Target (AST) production process and finally produce a functional description of the system which becomes a major part of the AST and which industry can use as a starting point for implementation. It is interesting to note that this approach is consistent with the way in which technological advances such as those proposed under the VHSIC programme will be exploited in that, as the functions are decomposed to their constituent sub functions, a level will be reached at which certain of the sub functions can be realised directly in silicon.

The method chosen for producing the functional decomposition must be self documenting and must provide readily understandable feedback to the system user so that the interactive nature of the system requirement definition phase can be capitalised upon. Furthermore, it must be easy to update the documentation when changes in requirement occur. The first need can be satisfied by using a technique based on diagrams rather than prose while the second aim can be met by the use of computer aids.

3.2 Methods of Producing the Functional Design

This section reviews the work performed to date on the problem of producing functional designs and indicates the extent to which the ideal approach to system design, shown in Fig 1, can be achieved. It must be stressed that the conclusions presented are tentative, not only because of the early nature of the work but also because the field itself is very young and does not possess the scientific rigour found in the more traditional engineering disciplines.

Most of the effort to date has been expended in the search for suitable tools, with the system analysis area undergoing the most scrutiny. This area was chosen because many design tools have been developed as aids to the system analyst for use during the process of transforming the customer requirement into software. It was felt that, because in many applications in which commercial systems are under development the hardware is relatively fixed, the process of defining and documenting the system software is very similar to that of defining and documenting the system. It was also decided that, as far as possible, only mature tools, which possess computer based support, should be used and it was likely that such tools would be found in the system analysis area.

In the event two techniques were discovered which largely met the requirements; SADT (Softech Inc, 1976) and SAFRA (BAe, 1980). Both were applied to a complex in-house project and the results compared. It is not possible to present the results of the work in detail in a paper of this length but they are fully documented elsewhere (L.T.J. Salmon, 1981, and M.A. Beeny, 1982). The following general points arose:

(a) SAFRA was more time consuming in its application because it was more formal and rigorous than SADT. Each functional level needed a detailed breakdown before the next level could be safely embarked upon whereas SADT allowed a rapid breakdown to occur.

(b) As a corollary of (i), it was found that the transition between the Functional Architecture and Conceptual Architectures was difficult to achieve smoothly in SADT because of the lack of rigour at higher levels. Ref (3) shows that the transition was made but the steps involved were somewhat subjective and difficult to justify logically. They were also, therefore, difficult to document.

(c) SAFRA does not lead to a clear delineation between the various architectures, rather, there is a gradual progression with overlapping areas between architectures. Nevertheless, philosophically at least, it does produce a breakdown similar to that shown in Fig 1.

(d) When applied to a complex system both techniques are not viable unless supported by computer aids which allow pictorial documentation to be produced and consistency checks to be performed automatically. Such aids do not replace the need for innovative thought on the part of the system designer but they do remove the tedium caused by the need to update system documentation manually after changes have been made in system requirement. It cannot be emphasised too strongly that without these aids both techniques are not usable.

(e) Both techniques suffer from limitations caused by the English language itself. It can be difficult to find sufficient unique names for the mass of data types and processes which exist in a large, complex system.

(f) It is self evident that the system analysts employed on the functional decomposition of an aircraft should, between them, possess a broad experience of avionic system engineering. A conflict exists, however, in that in order to apply a functional description technique to produce a Functional Architecture, the aircraft must be thought of and described in terms which are as abstract as possible, for reasons outlined in para 3.1. An analyst with a wide experience of avionic system engineering will tend to think in terms of implementation solutions rather than in terms of abstract requirements. The ideal system analyst will, therefore think abstractly, based on his experience, and be aware of this danger. Such people are difficult to find therefore much care must be exercised over the selection of staff for this task.

As a result of the above investigation SAFRA was chosen as the method upon which future work will be based. It is intended to apply the technique to the functional requirement of a complete aircraft project, not only to assess SAFRA more fully but also to validate the system design philosophy outlined in paras 2 and 3.1.

4 DESIGN REQUIREMENTS

To support the functional design, requirements for safety, mission effectiveness and vulnerability are needed. Often in the past, the approach to these design requirements has been to propose that future systems should be say an order of magnitude 'better' than current ones, or should be able to absorb one, two, or whatever, failures. Such proposals are not based on particularly rigorous assumptions, but are usually based on what the originator considered practical with the technology at the time, and may be too stringent. An approach based on cost-effectiveness reasoning is preferable, although there are many practical difficulties and it is not always possible. Moreover, cost-effectiveness reasoning often does not permit a simple universally applicable figure to be proposed, since, by definition, cost and effectiveness are dependent on the detailed design. General guidelines to determining optimum requirements can, however, be given.

4.1 Safety

In practice, the safety requirement is probably the most difficult one to specify and assess. Although it might be possible to apportion financial costs to accidents, and then derive a safety requirement from purely cost-effectiveness analysis, a less contentious approach is to reason that future aircraft should not be less safe than current ones.

The safety requirement can only be expressed in terms of the number of accidents which can be accepted. It is clearly too facile to suggest that we can tolerate no accidents, since even if this could be achieved, the resulting aircraft would probably be unacceptably expensive to purchase and maintain. On this basis, the safety requirement for future aircraft must be that they should be no less safe than the corresponding class of current in-service aircraft, with improvements being made in areas where these can be achieved without significant cost or complexity penalties.

Examination of accident records shows that in many cases one can only speculate on the cause of the accident. This, together with the very small sample sizes, produced much uncertainty in agreeing the current accident rate resulting from equipment failure. However, it would seem that, at worst, the major accident rate, due to equipment failures, for fast-jet aircraft, is 1 in 40,000 flying hours. Future systems should be designed to be no worse than this, and preferably show an improvement.

There is, of course, the additional difficulty, namely that of proving that a proposed solution will meet the safety requirements. If the proposed design is based on current techniques, recourse can be made to historical data. If new techniques are used, a failure mode and effect analysis (FMEA) will be necessary. The difficulty is further increased if pilot interpretation is involved, since the pilot reaction can be difficult to quantify or predict, and is influenced by factors such as workload. The most important area where pilot interpretation is involved, from a safety viewpoint, is the presentation of flight information to the pilot. Normally, in fast-jet aircraft, the pilot has two more or less independent channels of flight information, namely the head-up display and the head-down instruments. It can be shown that for typical systems, the pilot is statistically more likely to be placed in a potentially hazardous situation, not due to a failure of both channels, but by a non-obvious failure of one channel, when there is no visible horizon. From a safety aspect therefore, it is not the failure rate which is important, but a sub-set of this, the non-obvious (or insidious) failure rate. It is difficult in practice to obtain agreement on which failures are non-obvious but a reasonable agreement is possible. It is very much more difficult to determine the degree of hazard which should be apportioned to each non-obvious failure. After discussions with pilots (particularly on their experience of potentially hazardous failure), and examining failure and accident information, the authors have produced the following proposal for failures in systems which present flight information to the pilot:

It is sufficiently accurate to consider only two failure categories, (ie obvious and non-obvious), and two meteorological states (ie horizon visible and no horizon visible). The safety proposal for fast-jet aircraft is that the pilot should not be placed in a potentially hazardous situation due to a non-obvious failure of the flight information when there is no visible horizon, more frequently than once in 50,000 one-hour sorties.

There is very little information on the ability of a pilot to recover from potentially hazardous failures, largely because of the small sample size involved. The limited information acquired by the authors from discussions with pilots, suggests that the failure rates implied by the above proposal are likely to result in less than one major accident (due to failure of the flight information) in 1,000,000 one-hour sorties. This is compatible with the overall accident requirement of less than one major accident in 40,000 hours.

4.2 Mission Failure

The design requirement for mission failure is far more amenable to cost-effectiveness analysis. If failures in a given item of equipment result in say 1% of the ground attack missions being 'lost', then the effectiveness of the fleet is reduced by 1%, and it can be argued that up to 1% of the aircraft cost can be justified in removing this source of mission failure, by say duplicating that item of equipment. Thus, although no universal figure can be proposed, the approach to deciding whether or not a particular design has an acceptable mission failure rate is clear.

Two questions arise. Firstly, when we speak of cost, should this be the purchase price, the life-cycle costs, or what? The costs should, of course, be life-cycle costs, but the limited data which the authors have to hand suggests that the figure for the ratio of the life-cycle costs (LCC) to purchase price is approximately the same for a complete aircraft as for an item of complex avionics. Thus, at least for complex avionics, preliminary rough assessments can be made using purchase price. Secondly, is duplication the best approach, or should efforts be made to improve reliability, or should a lower accuracy, but less expensive standby system be incorporated? The cost-effectiveness analysis of these options is, at least mathematically, trivial, and is not pursued here. However, an important aspect of the design of future aircraft, particularly where off-base operation in small groups is envisaged, is the ability to continue to fly effective sorties following main equipment failure when spares are not available. In this context, depending on the detailed scenario envisaged a simple reliable and independent standby system might be more useful than duplicating items of main equipment.

4.3 Vulnerability

Vulnerability in this context is taken as being vulnerability to enemy action. The importance of vulnerability can be illustrated very simply. For a large fleet of aircraft, taking attrition rates per sortie of 1%, 5% and 10%, then, neglecting any limitations in repair facilities, the average numbers of sorties flown per aircraft, before all are 'lost', are respectively 100, 20 and 10.

The question thus arises as to how far can one justify measures to reduce attrition? It can be shown that, at a simple level, the answer is independent of the details of the scenario, other than a knowledge of the damage characteristics of the threat. If the attrition rate can be reduced by say 10%, the number of sorties increases by 10%, ie in the example above, if the attrition rates are reduced to 0.9%, 4.5% and 9%, the average number of sorties flown per aircraft rises to 110, 22 and 11 respectively. Thus, at a simple level, measures taken to reduce the vulnerability by 10% are equivalent to an increase in fleet size of 10%. A basis for a cost-effectiveness analysis is therefore established. It is, of course, necessary to predict the damage caused by the particular type of missile, shell, etc, but much experience has been built up over the years in this area.

5 AVIONICS MAINTENANCE COSTS

It is generally agreed that the reliability-dependent maintenance cost for complex avionics, when taken over the life of the equipment, is typically much greater than the original purchase price of the equipment, and it is necessary, in the early stages of equipment design, to design for minimum life-cycle costs. There is much less agreement on how we actually achieve this!

In order to contribute proposals on the way ahead, and to be able to assess the various opinions expressed, the authors needed to obtain background education on a breakdown of maintenance costs for avionic equipment currently in-service. Accordingly, 12 avionic line replaceable units (LRUs) for a current fast-jet aircraft were selected, and the maintenance man-hours expended in testing and defect rectification at the various servicing levels determined. These results were combined with the results of other studies, to produce the cost pie diagram of Fig 2. It must be emphasised that there was a large spread in the values for individual LRUs. The average values are presented in Fig 2.

For the 12 LRUs selected in this survey, the dominant costs are 3rd/4th line and spares. At 1st line (ie work carried out at the aircraft), activities are restricted to testing the system, and replacing defective LRUs: at 2nd line (ie work carried out in the repair bays on the airfield), rectification is typically confined to diagnosing the defect to module level, and replacing the defective module, while at 3rd and 4th line (ie work carried out in centralised RAF repair facilities, or in industry, respectively), defects are diagnosed to component level. Since equipment is usually designed so that defects to LRU and module level can easily be diagnosed, it is perhaps not surprising that 3rd/4th line costs (involving diagnoeie to oomponent level and replacement of the defective component) are relatively large.

Spare LRUs need to be held to supply 1st line, and spare modules to supply 2nd line. The cost of the sparee holding therefore depends upon the reliability of the LRU and the reliability of the individual modules, the oost of the LRU and individual modules, and the length of time that the LRU and modules are "loet in the repair chain".

Assuming that future avionics will have a similar oost pattern to the 12 LRUs chosen in this etudy, then it is clear that a broad view must be taken if life-cycle costs are to be reduced. There is little point in concentrating on just one aspect say improved testability for 1st and 2nd line diagnosis - which ie a suggestion frequently proposed - if this is likely to result in increased costs elsewhere. Repair costs can only be minimised by designing the system and LRUs such that the total repair costs, considered as the sum of the contributions from each of the servicing levels, are minimised.

There is therefore a need, in future system design, to consider not only LRU reliability, but the 'total cost' of repairing a defect. The detailed equipment design must be such as to minimise this total cost of repairing a defect. Special attention should be given to the 3rd/4th line costs (locating a defect to component level, and subsequent repair). The cost of spare holdings of modules is aleo influenced by the detailed design. For instance, if moet of the purchase cost and the unreliability of an LRU arose from a relatively small number of modules in that LRU, the cost of spare modules necessary to supply the 2nd line eervicing would be greater than if the cost and unreliability were divided equally between all the modulee. Thus oomparative studies of alternative detailed designs should be undertaken by the manufacturer in the early deeign stages to ensure that the eventual eolution has minimum LCC.

6 CONCLUSIONS

The work on functional design has shown much promise when applied to modestly-sized in-house tasks, but there is a need to test the practicality of the approach by tackling a complete aircraft, and seeking involvement from a wider range of specialists who have not had prior experience of this design approach. Similarly, the proposals for design requirements and for minimising LCC, although believed to be sound in themeelves, need to be applied to worked examples to assess whether their rather general approach will limit the extent to which they are of value in practice.

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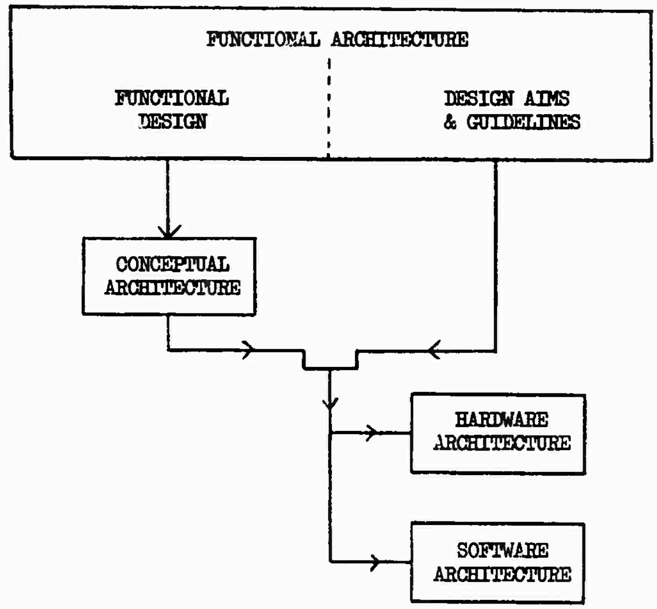
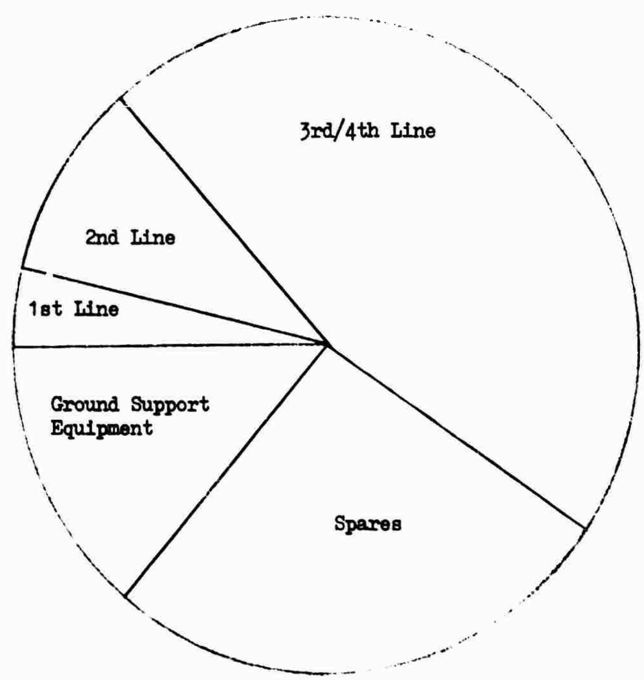


Fig 1 SYSTEM ARCHITECTURES



<u>Definitions</u>

1st line: work undertaken on the aircraft

2nd line: work undertaken in the repair bays at the aircraft station

3rd line: work undertaken in centralised repair bays, generally serving several stations

4th line: work undertaken by industry

Fig 2 BREAKDOWN OF RELIABILITY-DEPENDENT MAINTENANCE COSTS FOR COMPLEX AVIONICS, EXPRESSED RELATIVE TO THE EQUIPMENT PURCHASE PRICE

VERS UNE MODULARITE DU LOGICIEL

CONCUE POUR LES BESOINS DE L'UTILISATEUR

P. CATEL

ELECTRONIQUE SERGE DASSAULT

55 quai Carnot

92214 SAINT-CLOUD

RESUME

Après avoir resitué le contexte du logiciel d'un calculateur principal de système avionique, ce document présente la démarche accomplia par ESD pour la recherche d'une modularité du logiciel adaptée aux besoins de l'utilisateur. Cette démarche s'est déroulée en deux phases :

- La première concernait des applications de taille moyenne (jusqu'à 64 K mots) et a permis de définir une structure du logiciel et des règles de découpage du problème.

- La seconde est apparue à l'occasion du démarrage d'une nouvelle application, d'un volume plus important, devant être la base d'une famille d'applications importante.

  Une étude, manée conjointement avac le cpécificateur du logiciel (le maître d'oauvre du système), a permis différentes améliorations, aussi bien sur le plan de la structure que des méthodes et des règles de découpage, dans la but d'obtenir une récupérabilité parfaite d'entitéa de logiciel. Elle s'est concrétisée par la mise en oeuvre de nouveaux outils, et des extensions de la Machine Virtuella du calculateur utilisé.

1. INTRODUCTION

L'ELECTRONIQUE SERGE DASSAULT (ESD) est spécialisée dans l'étude, le développement et la fabrication d'équipements élactroniques de pointe, tant dans le domaine militaire que dans le domaine civil.

L'effectif da l'ESD est de 3200 personnes, dont 1800 ingénieurs et cadrea. L'informatique aérospatiale (calculateurs, bua numériques, systèmas digitaux, logiciels de base et d'application) constitue une dea activités principales da l'ELECTRONIQUE SERGE DASSAULT : 20 à 25 % du chiffre d'affaires est réalisé dans ce domaine.

Depuis 1965, époqua à laquelle l'ESD a conçu le premier calculateur embarqué européen utilisant des circuits intégrés, les missiles balistiques français sont équipés de calculateurs universals ESD, puis ESD-SAGEM à la suite d'accords de coopération signés entre les deux sociétés.

En 1976, l'accroissemant des besoins en matière de puissance de calcul conduit l'ESD à promouvoir en France da nouvelles technologies da composants et de circuits pour créer una nouvella génération de calculateurs universels :

- 1084 pour missilas balistiquas,
- M182 pour avions MIRAGE F1,
- 2084 pour avions MIRAGE 2000.

Le système de transmission des informations numériques à bord de ces avions a lui aussi été développé par ESD : c'est le bus numérique GINA (DIGIBUS), normalisé depuia septembre 1982 par la Ministère de la Défense français sous la référence GAMT101.

L'ESD réalise également tous les logiciels de base et, sous la maîtrise d'oeuvre de ses clients, la plupart des logiciels d'application concernant ses propres calculateurs aérospatiaux. L'introduction de la nouvelle génération de calculateurs ESD en tant que calculateurs principaux des avions MIRAGE F1 et MIRAGE 2000 a considérablement développé cette activité logiciel.

Les logiciels, dans les applications avioniques, présentent des caractéristiques spécifiques : les aspects les plus marquants sont la fiabilité, et les contraintes de réalisation (concision du volume mémoire et charge de calcul) qui sont encore sensibles avec les matériels disponibles aujourd'hui.

Cependant, le volume sans cesse croissant de ces logiciels fixe une nouvelle priorité, celle de pouvoir réutiliser les parties les plus grandes possibles de logiciels déjà existants pour réaliser le logiciel d'un nouveau système.

Ce besoin se fait sentir non seulement au niveau de la réalisation proprement dite du logiciel, mais aussi -et peut-être surtout- pour réduire l'effort d'intégration et de mise au point (au sol et au vol) du système global.

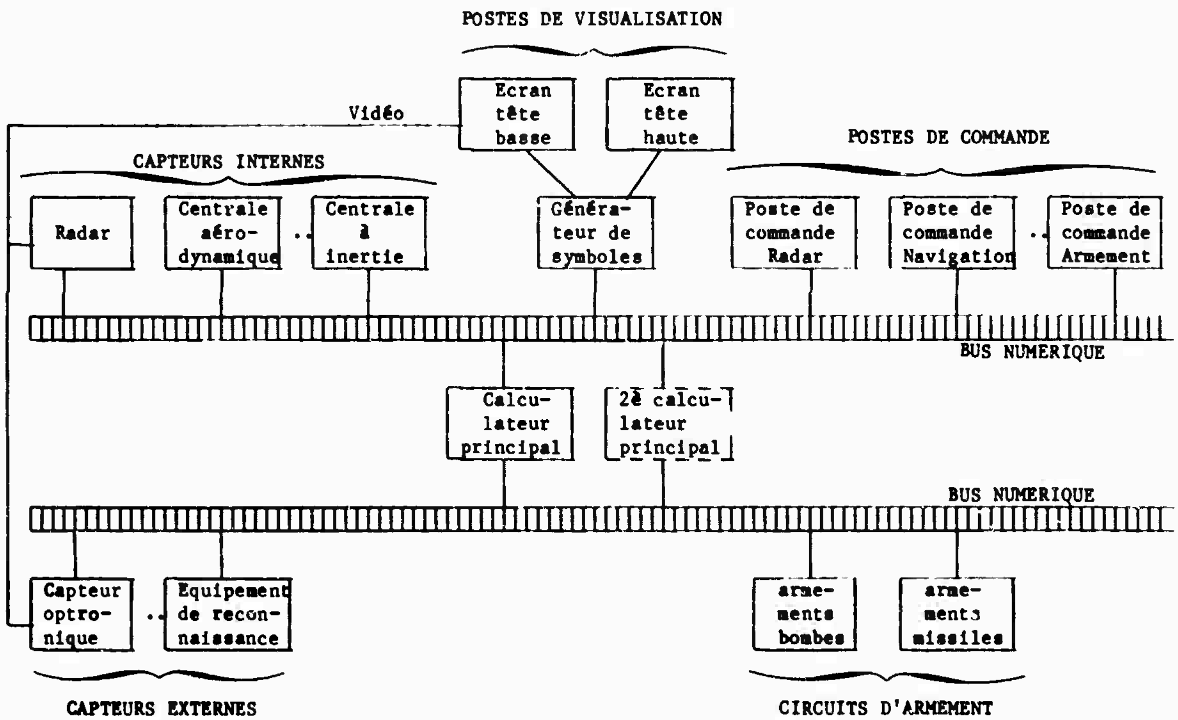
La réponse est apportée par une conception modulaire du logiciel développé. Ce document présente notre approche de ce problème, qui peut être découpée en deux phases. La première concerne des logiciels développés jusqu'en 1981, d'une taille moyenne (volume mémoire des calculateurs limitée à 64 K).
La seconde phase est liée au développement de nouveaux logiciels, dont le volume à terme sera beaucoup plus important, ce qui nous a amené à adapter à la fois les caractéristiques de nos calculateurs et nos méthodes de réalisation du logiciel.

Avant de décrire ces deux phases, nous allons rappeler le contexte dans lequel se situe le logiciel du calculateur principal, puis définir ce qu'est la modularité d'un logiciel.

2. CONTEXTE DU LOGICIEL D'UN CALCULATEUR PRINCIPAL

2.1. Fonctions du Calculateur Principal dans un système d'armes avionique

Le système de navigation et d'attaque (SNA) d'un avion de combat moderne peut être très schématiquement illustré, dans son principe général, par la figure suivante :



Parmi les principaux équipements du SNA, on distingue :

- des capteurs fixes ou montés en pod : centrale à inertie, centrale hydrodynamique, radar, etc...
- des postes de visualisation : écran tête basse, viseur tête haute, etc...
- des postes de commande : pour la navigation, l'armement, le radar, etc...
- des circuits d'armements : pour bombes, canons, missiles, etc...

Bien que tous ces équipements comportent une part de plus en plus grande d'électronique numérique, c'est-à-dire de processeurs spécialisés et très intégrés au matériel, les calculs effectués y sont de nature différente de ceux du calculateur principal : ils sont spécifiques de l'équipement, contribuent directement à ses performances et ne traitent généralement que des données locales.

Au contraire, le logiciel du calculateur principal intervient au niveau global du système de façon relativement indépendante des caractéristiques particulières des équipements. Il assure deux types de fonctions :

- des fonctions de gestion centralisée (échanges d'information, surveillance du fonctionnement d'ensemble) :

  Le schéma fait apparaître le rôle particulier du (ou des) bus numérique ou "digibus" auquel sont connectés la plupart des équipements du système d'armes. Les informations échangées entre ces équipements transitent sur cette liaison sous forme numérique et suivant un mode de multiplexage temporel à haute fréquence. Les liaisons directes entre équipements sont de plus en plus rares ; il en subsiste encore quelques unes pour différentes raisons (survivance de techniques analogiques, débit d'informations, sécurité).

  La gestion du bus numérique est assurée par le calculateur principal. Celui-ci peut être dédoublé pour des raisons de fiabilité, en particulier pour assurer la gestion du bus en cas de défaillance du premier.

- des fonctions opérationnelles : à partir des données élaborées par les capteurs et des ordres introduits manuellement sur les postes de commandes par le pilote, le calculateur principal effectue un certain nombre de traitements permettant d'assurer les missions opérationnelles de l'avion : navigation, attaque Air-Sol, attaque Air-Air ; suivant la mission, certains résultats de calculs sont adressés à des équipements comme les circuits d'armement, d'autres informations sont présentées au pilote sur les postes de visualisation. Dans quelques cas, une partie de ces traitements est effectuée par des calculateurs implantés dans le radar ou le viseur par exemple. La présence d'un second calculateur principal permet d'y implanter un certain nombre de traitements, augmentant ainsi la capacité globale de calcul au niveau système.

2.2. Caractéristiques du logiciel

La présence d'un calculateur principal dans un SNA offre un certain nombre d'avantages. Par sa structure de calculateur universel, il va apporter en effet une grande puissance de calcul, mais il va également constituer l'élément de souplesse privilégié du SNA : c'est par des adaptations de son logiciel et, dans certains cas de son matériel (au niveau des coupleurs), que l'on va pouvoir intégrer dans le SNA des équipements existants sans modification de ceux-ci (particulièrement les capteurs et les armements dont les techniques très spécifiques font qu'il est en général plus pénalisant de les modifier, cela entraînant des mises au point souvent longues).

Par ailleurs, il va assurer un rôle primordial dans les traitements liés à la mise en oeuvre du SNA, et particulièrement les problèmes de dialogue homme-système. Notamment, il assure la gestion des équipements à usage général, comme les postes de visualisation et les postes de commande, et les configurant selon les spécificités de chaque mode dont le système est capable.

Ces 2 aspects ont comme conséquence que les logiciels des calculateurs principaux supportent de très nombreuses modifications tout au long de leur cycle de vie. En effet, d'une part ils doivent suivre les évolutions des définitions des équipements, d'autre part les solutions aux problèmes ergonomiques sont souvent longues à mettre au point. Le taux courant, sur nos projets, est de recevoir environ 1.5 demandes d'évolutions par jour ouvrable, pendant toute la phase de développement. Ces évolutions permanentes ne favorisent pas, bien sûr, la standardisation du logiciel.

Sur un autre plan, la tendance générale est une sophistication toujours plus grande des systèmes, due à des accroissements de leurs possibilités pour la mise en oeuvre d'armements de plus en plus nombreux, et de plus en plus complexes. Cela a en particulier comme conséquence une recherche de l'allègement des tâches du pilote, se traduisant entre autre par des élaborations d'informations toujours plus synthétiques, et également l'automatisation de certaines prises de décision.

Ces évolutions se traduisent par un accroissement permanent du volume du logiciel des calculateurs principaux. Il en résulte une évolution dans sa perception par les utilisateurs. D'une approche initiale où la réaction normale à une demande nouvelle était :

- "ça ne touche que le logiciel, il n'y a pas de problème", on tend vers une attitude opposée, où le logiciel apparait comme quelque chose de secret, difficile à maîtriser, en évolution permanente et dont le coût est de plus en plus préoccupant.

Le réalisateur du logiciel a autant de difficultés à expliquer qu'une évolution est faisable, sans obligatoirement tout remettre en cause, qu'il en avait autrefois à faire comprendre, qu elle n'était pas aussi simpliste que ses interlocuteurs avaient tendance à le supposer.

Il est certain qu'un logiciel est complexe, ne serait-ce que par le nombre d'informations traitées : le calculateur principal d'un système actuel doit, par exemple, recevoir de l'ordre de 900 informations différentes, logiques ou numériques, pour en générer environ 1300.

Face à un tel problème, il existe une seule solution : "diviser pour régner" ou réduire le problème complet en sous-problèmes suffisamment petits pour que chacun puisse être maîtrisé. D'où la nécessaire modularité du logiciel.

Cette modularité va également être mise à profit pour permettre la récupération d'éléments entre un logiciel et un autre. Cette démarche est cependant beaucoup plus difficile à faire passer dans les faits, car elle nécessite une approche cohérente de la part de toutes les personnes impliquées dans la chaîne, du pilote au programmeur.

2.3. Interlocuteurs impliqués dans le développement d'un logiciel

Le développement d'un logiciel fait intervenir deux responsabilités :

- le Spécificateur du logiciel est l'avionneur, maître d'oeuvre du système. Son rôle est de concevoir le Système de Navigation et d'Armements, ce qui se fait en deux étapes :

  . Définition globale du système : cette étape concerne le niveau système, et le projet logiciel y est seulement identifié. Elle consiste à :

  - définir le système du point de vue de ses utilisateurs, en décrivant globalement ses FONCTIONS OPERATIONNELLES, ses interfaces avec l'environnement, ses performances,

  - identifier les SOUS-ENSEMBLES matériels et logiciels du système et mettre en évidence le rôle de chacun d'eux dans la réalisation de chaque fonction opérationnelle.

  Cette étape est concrétisée par le document de SPECIFICATIONS GLOBALES DU SYSTEME.

  . Définition opérationnelle du logiciel :

  La définition opérationnelle du logiciel ne peut s'effectuer que dans le cadre d'une DEFINITION DETAILLEE DU SYSTEME qui consiste à :

  - décrire chaque fonction opérationnelle de façon complète et précise,

  - répartir, pour chaque fonction opérationnelle, les traitements entre les différents sous-ensembles,

  - déterminer les interfaces entre les sous-ensembles.

  Les travaux relatifs au sous-ensemble logiciel, objet du projet, constituent la DEFINITION OPERATIONNELLE DU LOGICIEL.

  La part incombant au logiciel dans chaque fonction opérationnelle est appelée CHAINE LOGICIELLE.

  Les traitements de chaque chaîne logicielle sont décrits d'un point de vue opérationnel (non informatique) de la manière la plus complète et la plus précise possible. En particulier, tous les choix relevant de la responsabilité du demandeur sont explicitement définis.

  Cette étape est concrétisée par le cahier des charges du logiciel, constitué par :

  - les SPECIFICATIONS OPERATIONNELLES DU LOGICIEL,

  - les SPECIFICATIONS DES INTERFACES DU LOGICIEL.

- Le Réalisateur du logiciel va en assurer la conception et la réalisation.

  Si les responsabilités sont nettement marquées, il est très profitable que le transfert des tâches entre demandeur et réalisateur se fasse plus progressivement. En particulier, le réalisateur va participer à la phase de définition opérationnelle du logiciel, et le spécificateur va au minimum contrôler les résultats de la phase de définition fonctionnelle du logiciel, qui est la première menée sous la responsabilité du réalisateur.

3. DEFINITION DE LA MODULARITE DU LOGICIEL

3.1. Définition

Un produit est dit modulaire à partir du moment où il est constitué d'éléments indépendants, dont l'assemblage conduit à un tout cohérent. Dans le cas d'un logiciel, on est amené en fait à concevoir une structure hierarchisée, dans laquelle, lorsqu'on part des composants élémentaires, il existe plusieurs niveaux de regroupement successifs.

Le premier bénéficiaire de la modularité est le réalisateur. Celle-ci va, en effet lui permettre de contrôler le développement du logiciel et aussi de tenir les objectifs de fiabilité, chaque niveau d'intégration constituant un niveau de test.

Le deuxième apport de la modularité est la possibilité de modifier un élément à l'un quelconque des niveaux, sans remettre en cause les autres, et donc d'apporter une grande souplesse pour l'évolution d'un logiciel.

Dès lors, le problème de la modularité du logiciel doit être abordé sur deux plans :

1) Le plan structurel

C'est le problème du contenant, autrement dit, il convient de définir ce que seront les différents niveaux auxquels des éléments de logiciel seront manipulables. Il y a là une première source de difficultés : en effet, tout le monde sait de quoi on parle lorsque l'on nomme des différents éléments d'un matériel : une carte, un hybride, cela se voit et se touche. L'aspect raccordement (prises, connecteurs, pattes) est perçu facilement.

Pour le logiciel, par contre, la situation est différente, pour au moins 2 raisons :

- La première est qu'un logiciel ne se voit pas. L'appréhension se fait sur le papier, dans des listings ou différents documents de description, dont la langue est plus ou moins rébarbative, mais rebute en général tout non informaticien.

- La deuxième est qu'il n'y a pas un vocabulaire universel définissant des éléments de structures dûment identifiés. Bien sûr, tout le monde parle de module, mais quand on regarde de près, on s'aperçoit vite que ça ne recouvre jamais les mêmes notions.

2) Le plan fonctionnel

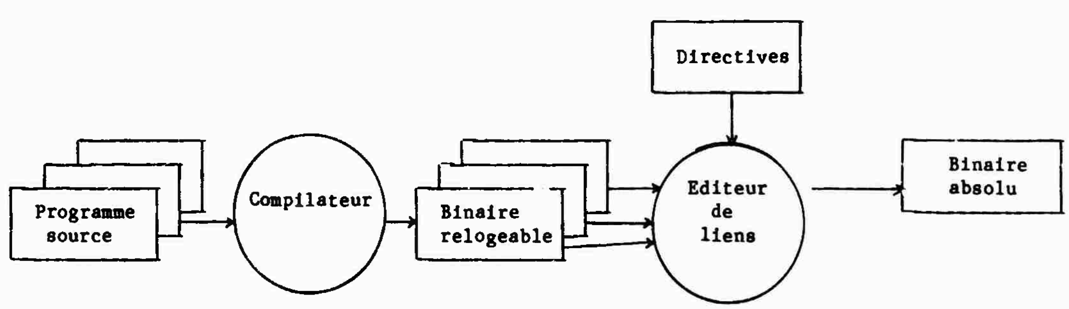
C'est le problème du contenu, c'est-à-dire celui qui consiste à définir le rôle de chaque élément de la structure. Le problème essentiel, ici, est de faire coïncider les exigences au niveau de la réalisation du logiciel, liées à la technique informatique avec les besoins des utilisateurs qui manipulent des notions qui peuvent être a priori toutes autres.

En fait les premières personnes concernées par la modularité du logiciel ont été les réalisateurs de celui-ci. Leur premier souci était de résoudre les difficultés liées à la réalisation d'un logiciel avionique : fiabilité, testabilité, et également les aspects industriels : tenue des délais, des coûts de réalisation, prévision et suivi des charges de calcul et des volumes mémoire.

Cependant, la modularité du logiciel n'est valable que si les deux aspects du problème sont correctement traités.

3.2. Réutilisation d'un logiciel

Une seconde notion générale reste à préciser, celle de "récupération" d'un logiciel existant. Classiquement, un logiciel est obtenu en deux étapes, comme schématisé sur la figure ci-dessous.



La première étape est la compilation. Elle consiste à transformer un programme source, rédigé en différents langages (LTR, macroassembleur, assembleur, ...) en un programme binaire relogeable. Cette compilation est réalisée indépendamment sur chacune des unités élémentaires de logiciel, on a donc le même nombre d'entités "binaire relogeable" que d'entités "source".

La seconde étape, réalisée par l'éditeur de liens, consiste à réunir toutes les entités nécessaires (leur liste est définie par des directives données à l'éditeur de liens) pour composer un programme exécutable. L'éditeur de liens peut alors générer, un binaire absolu, c'est-à-dire un programme directement chargeable dans le calculateur.

Le meilleur niveau de récupération est celui qui consiste à reprendre des binaires relogeables. Cela permet en effet de s'affranchir du coût et des délais nécessaires pour une compilation. Il n'en reste pas moins que la réutilisation de programmes source est un second niveau envisageable, à partir du moment où il se situe en aval des interventions humaines.

Les directives données à l'éditeur de liens étant également décrites par le programmeur, on aura également intérêt à en récupérer un maximum en passant d'un projet à un autre.

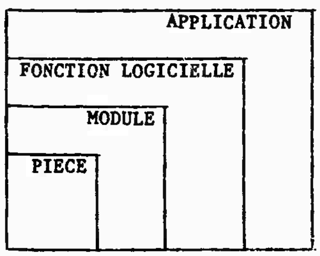
4. PREMIERE GENERATION DE LOGICIELS

Pour réaliser nos premiers logiciels avioniques, nous avons donc eu à définir l'architecture du logiciel, sur les plans structurel et fonctionnel.

4.1. Plan structurel

1) Niveaux de structure

Nous avons défini une structure à quatre niveaux, schématisée par la figure ci-dessous.



- L'application est l'ensemble du logiciel implanté dans un calculateur. Elle est perçue par l'utilisateur comme une boîte noire, échangeant des informations avec l'extérieur et assurant une certaine fonction de transfert entre ses entrées et ses sorties. Au niveau de la production de logiciel, elle est caractérisée par un fichier donnant la liste des fonctions logicielles la composant et par un fichier de binaire absolu. Ces deux fichiers sont référencés avec le même nom et le même numéro de version (la seule différence étant leur type). L'application est bien entendu validée par la dernière étape de test.

- La fonction logicielle est le premier niveau de découpage. Si on fait un parallèle avec la structure d'un matériel, on peut l'assimiler à une carte d'un équipement. Il s'agit d'une entité assurant un rôle fonctionnel donné. Il lui est associé un jeu de paramètres en entrée et un jeu de paramètres en sortie. Le souci prédominant lors de sa définition est l'homogénéité du rôle qu'elle doit jouer. Le seul souci informatique est la notion de taille de logiciel associé, qui se situe généralement dans une fourchette de 3000 à 6000 mots. Avoir des fonctions logicielles trop grandes augmente leur difficulté, donc rendent plus difficile le test. Cela diminue aussi leur chance de pouvoir être standardisées. A l'inverse, une taille trop petite multiplierait leur nombre, augmentant ainsi notablement les difficultés de l'intégration finale au niveau application et limiterait alors les bénéfices d'une réutilisation de certaines fonctions logicielles déjà validées.

  En ce qui concerne la production de logiciel, une fonction logicielle est caractérisée par un fichier contenant la liste des pièces la constituant (utilisée en tant que directives pour l'éditeur de liens) et identifiée par un nom et un numéro de version. Chaque fonction logicielle est validée séparement, au cours de l'étape de tests fonctionnels.

- Le <u>module</u> eat le troisième niveau, de découpage. Son existence est liée à des modifications esaentiellement informatiques. Un module contient en effet toute la partie d'une fonction logicielle devant être exécutée sous une même condition d'activation (par exemple tous les traitements cycliques devant être exécutés à une fréquence donné).
  En général, un module ne sera pas un élément réutilisé facilement. Il ne joue pas en effet un rôle fonctionnel bien défini. Par contre, son rôle est primordial au niveau de la technique informatique, car il constitue une entité d'exécution : il possède un point d'entrée et un point de sorite, un jeu de paramètres en entrée et un jeu de paramètres en sortie. La somme des paramètres d'entrées-sorties des différents modules d'une fonction logicielle constitue l'interface de cette fonction logicielle.

  En ce qui concerne la production de logicel, un module est caractérisé par une entité de code, dont le rôle est d'assurer l'enchaînement des différentes pièces du module à l'exécution du programme.

- <u>La pièce</u> est le composant élémentaire, la brique du logiciel. Sa taille eat volontairement limitée de l'ordre d'une cinquantaine d'instructions source. Une pièce joue un rôle fonctionnel défini, est exécutable en un seul tenant (un point d'entrée, un point de sortie) et possède une interface d'entrée-sortie bien définie.

  Par ailleurs, chaque pièce est compilable séparément. Il lui correspond donc, au niveau de la production de logiciel, deux fichiers : fichier de langage source, et fichier binaire relogeable. Ces deux fichiers portent le même nom et le même numéro de version (seul le type diffère). Enfin chaque pièce est testée et validée séparément. La taille limitée d'une pièce permet d'en assurer un test quasiment exhaustif, ce qui est primordial pour obtenir la fiabilité recherchée pour l'ensemble de l'application.

  La taille restreinte d'une pièce fait qu'elle joue un rôle bien délimité, ce qui augmente ses possibilités de réutilisation dans plusieurs logiciels différents.

2) <u>Echanges d'information</u>

L'élément primordial, dans le choix de méthodes de passage d'informations entre les différentes entités de logiciel, a été un souci d'optimisation. Certains des logiciels que nous avions à réaliser l'étaient pour des systèmes équipés d'un seul calculateur principal, et le volume mémoire était donc obligatoirement limité à 64 K. Par ailleurs, le prix de ces mémoires n'encourageait pas non plus à de trop grandes largesses. Enfin, compte tenu de l'ensemble des traitements à réaliser, une certaine concision en charge de calcul était également nécessaire.

Toutes ces raisons nous ont amenés à recourir à des zones de données communes, accessibles directement par toute pièce utilisatrice.

Nous avons alors défini deux niveaux de commun :

- Un commun général contenant toutes les données d'interface du calculateur avec l'extérieur, et toutes les données en interface des fonctions logicielles.

- Des communs de fonction logicielle, chacun regroupant toutes les données internes d'une fonction logicielle, c'est-à-dire en interface de ses différentes pièces.

4.2. <u>Aspect fonctionnel</u>

La structure étant définie, il reste à définir le rôle que doit assurer chacun de ses éléments. En fonction de notre méthodologie, MINERVE, ces travaux sont réalisés au cours de deux étapes successives.

- L'étape de définition fonctionnelle consiste à reprendre les spécifications opérationnelles (le cahier des charges) du logiciel et à rédiger les spécifications fonctionnelles de celui-ci. C'est donc au cours de cette étape que sont définies les différentes fonctions logicielles.

- L'étape de conception globale a pour rôle de définir les éléments constitutifs suivants du logiciel (modules, pièces) et de définir leurs interfaces.

En pratique, la répartition en modules des traitements nécessaires pour l'accomplissement d'une fonction logicielle donnée ne pose pas de gros problèmes. Le critère "condition d'exécution" est en effet un concept précis, si bien que le concepteur n'hésite pas pour implanter un traitement dans le module adéquat.

Par ailleurs, les pièces sont d'une taille suffisamment réduites pour qu'elles possèdent généralement une bonne cohérence fonctionnelle.

Par contre, la définition des fonctions logicielles est plus complexe. Elle recoupe en effet des préoccupations d'analyse du problème à traiter, et de synthèse à un niveau relativement élévé . Les critères de choix sont multiples, et le concepteur doit en fait obtenir le meilleur compromis entre plusieurs facteurs dont certains sont contradictoires :

- Possibilités d'adaptation du logiciel à des évolutions opérationnelles (modification, suppression ou ajout de modes opérationnels) ou des évolutions des équipements du système (modification, suppression ou refonte de certains d'entre eux).

- Isolement des traitements dépendant directement de chacun des autres équipements du système, par rapport aux traitements caractéristiques d'un mode opérationnel dans le but de standardiser ces derniers.

- Souci d'optimisation, par mise en commun et implantation unique dans le calculateur de traitements nécessaires à l'exécution de plusieurs modes opérationnels.

- Possibilité de réaliser des livraisons partielles, c'est-à-dire de livrer un logiciel composé d'un nombre réduit de fonctions logicielles, qui permette néanmoins au système d'exécuter un certain nombre de missions opérationnelles.
  Cette possibilité est importante car elle autorise une imbrication des phases de spécifications, de réalisation du logiciel, et d'intégration du système, réduisant ainsi les délais de développement.

- Possibilité de définir, pour chacune des fonctions logicielles, des modes de fonctionnement dégradés. Le rôle de ceux-ci est de fournir les mêmes paramètres de sortie que dans le mode de fonctionnement normal (avec une précision moins bonne) lorsqu'un certain nombre d'informations en entrée sont elles-même dégradées ou manquantes. Cela permet d'assurer une continuité de fonctionnement du système en cas de panne d'équipements.

Appliquer aux logiciels avioniques, ces notions ont conduit à définir quatre grands types de fonctions logicielles :

- Les fonctions logicielles "de servitude", dont le rôle est de permettre le fonctionnement du calculateur (moniteur, autosurveillance) ou du système (gestion des bus, surveillance des équipements et signalisation de leurs pannes).

- Les fonctions logicielles "générales", dont le fonctionnement est indépendant ou peu dépendant du mode système en cours. Certaines assurent une interface avec les capteurs : prétraitement des données en entrée du calculateur de façon à élaborer les informations sous une forme interne standardisée, mais aussi mise en forme définitive des informations retournées à ces mêmes capteurs pour en commander le fonctionnement. D'autres assurent des fonctions communes à plusieurs modes opérationnels différents, comme l'acquisition d'objectifs par exemple.

- Les fonctions logicielles "spécifiques" des modes opérationnels devant être assurées par le système : navigation, différentes conduites de tir des armes air-air et air-sol, reconnaissance, aide à la maintenance sol, etc...

- Enfin, les fonctions logicielles "de synthèse", assurant la coordination des différentes fonctions précédentes pour obtenir un fonctionnement cohérent du logiciel global. Dans ce cadre, sont en particulier assurées les synthèses des différentes informations à destination des équipements multi-modes : postes de commandes, viseurs tête haute ou tête basse. Ces synthèses sont élaborées à partir des informations délivrées par les différentes fonctions générales ou spécifiques actives.

4.3. Bilan de cette première approche

Nous avons réalisé, entre 1977 et 1982, plus d'une quinzaine de logiciels pour des systèmes différents selon les principes décrits ci-dessus.

Ceux-ci se sont toujours avérés applicables, et la structure des premiers logiciels n'a jamais été remise en cause par la modification d'autres équipements, ni par l'ajout de nouvelles fonctions opérationnelles. Cette modularité a été également un élément prépondérant dans la possibilité d'intégrer les très nombreuses demandes de modifications que nous évoquions au paragraphe 2. De même, plusieurs applications différentes ont pu être déduites les unes des autres à un coût beaucoup plus faible que celui du développement de l'application mère.

Cependant, lorsqu'on arrive au niveau du détail, la situation n'est pas aussi bonne que l'on pourrait l'espérer. Il n'existe guère d'éléments rigoureusement identiquea entre deux logiciels. Les applications sont déduites les unes des autres, plus que composées à partir d'éléments communs.

Ce phénomène tient à trois causes principales :

1) Un problème spécifiquement informatique, tenant de l'utilisation de communs pour assurer les échanges d'information entre les différentes entités de logiciel. Le commun général entre autre est spécifique de chaque application, or il influence le code binaire relogeable de chaque pièce. La récupération ne peut donc se faire au mieux qu'au niveau de langage source.

2) Des évolutions de détail très nombreuses en passant d'un système à un autre. Ces évolutions portent à la fois sur la définition des autres équipements du système (nous avons là finalement beaucoup plus à tenir compte des petites "améliorations" que de changement complet d'un type d'équipement) et sur les spécifications des modes opérationnels. Toutes ces évolutions de détail, lorsqu'elles sont cumulées, font qu'il devient difficile de conserver intacts de nombreux éléments du logiciel.

3) Un manque de perception de la structure interne du logiciel existant par les utilisateurs, que ce soit au niveau des équipes établissant les spécifications opérationnelles qu'au niveau des équipes d'essais du système au banc d'intégration et en vol. Le manque de perception est probablement lié en partie à l'aspect un peu rébarbatif de la documentation associée au logiciel pour des non informaticiens. Le résultat est sûrement une sensibilisation réduite à l'aspect réutilisation de partie de logiciels existants au moment de la définition d'un nouveau système.

5. EVOLUTIONS RECENTES

Le réexamen de l'architecture de nos logiciels avioniques a été provoqué par l'occurence simultanée de plusieurs évènements de nature différente :

- Démarrage d'une application nouvelle, devant évoluer largement dans l'avenir. Cette application sers en fait la base (aussi bien sous l'aspect missions possibles au jeu d'équipements) d'une famille de systèmes, base à laquelle devront pouvoir s'ajouter de nombreuses options.

- Accroissement des possibilités du calculateur, la taille mémoire devant désormais dépasser le seuil des 64 K mots. Cela amenait à reprendre certains éléments, en particulier étendre la capacité d'adressage de la machine virtuelle et adapter le programme d'éditions de liens.

- Souci de plus en plus important de pouvoir récupérer intégralement des parties de logiciel existant, pour en tirer un maximum de bénéfice aussi bien au niveau de la réalisation du logiciel que de l'intégration et la validation du Système de Navigation et d'Armement global.

Une équipe commune maître d'oeuvre du système - réalisateur du logiciel a donc mené une étude sur ce problème. La première étape a consisté à définir clairement les objectifs nouveaux que l'on cherchait à atteindre par la modularité du logiciel.

Elle s'est poursuivie par la définition de nouvelles solutions :

- sur le plan structurel,
- sur les plans fonctionnel et opérationnel.

Enfin, les moyens d'une meilleure circulation de l'information entre spécificateur et réalisateur du logiciel ont été établis.

5.1. Définition de nouveaux objectifs

Récupérabilité du logiciel : elle constitue l'objectif le plus prioritaire. Cette récupérabilité doit être intégrale, et suffisamment formalisée pour qu'elle puisse éviter une nouvelle validation que ce soit au niveau des essais d'intégration du système au sol ou au niveau des essais en vol. Une condition est donc qu'il doit y avoir la meilleure correspondance possible entre les entités opérationnelles (les éléments du découpage de l'application abordée avec le point de vue de l'utilisateur) et les entités fonctionnelles. En outre, il est souhaitable de pouvoir donner à ces entités fonctionnelles les possibilités de réglage, clairement isolées, de façon à pouvoir les adapter à chaque cas particulier sans en reprendre la programmation proprement dite.

Amélioration de la visibilité du logiciel pour le spécificateur : celui-ci devra en effet appréhender la structure interne du logiciel, pour différentes raisons :

- Adapter les tests d'intégration du système, en ne considérant plus le logiciel comme une seule "boîte noire", mais comme plusieurs juxtaposées. Le but est de réduire le nombre de tests nécessaires au niveau système après une modification du logiciel.

- Prendre en compte la structure du logiciel pour concevoir des évolutions de système (modifications ou ajouts), de façon à en minimiser les coûts.

  Une demande précise était qu'il fallait pouvoir établir les correspondances entre les différents éléments du découpage au niveau opérationnel, et les différentes entités du logiciel.

Continuité avec les applications existantes : la prise en compte de nouveaux objectifs devait se faire en tenant compte de l'existant, aussi bien pour ce qui concernait le contexte de réalisation (moyens de développement et de test ; en particulier il n'y avait pas d'autre choix possible que de continuer à utiliser le compilateur LTR, le langage de haut niveau de nos précédentes applications, bien éprouvé) que pour des problèmes de coût et de délais : il était inenvisageable de réaliser in extenso une application nouvelle.

5.2. Evolutions sur le plan structurel

Elles sont au nombre de 3 :

- Création d'un cinquième niveau de découpage, entre application et fonction logicielle : le programme.

- Définition d'un langage de description de modules, et réalisation d'un interpréteur agissant en tant que préprocesseur du compilateur LTR.

- Extensions de la machine virtuelle des calculateurs avec un mode d'adressage "paramètre".

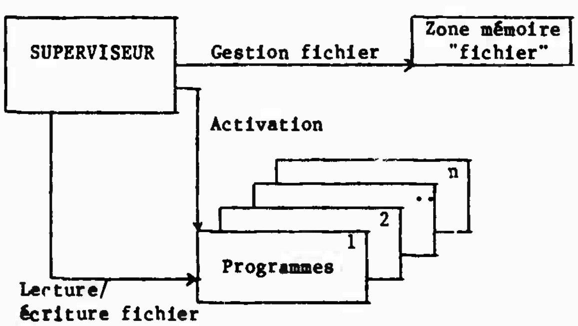
5.2.1. Cinquième niveau de découpage : le programme

L'objectif est de pouvoir diviser l'application totale en un certain nombre d'éléments rigoureusement indépendants au niveau de l'exécution, simplement juxtaposés au sein de la mémoire du calculateur.

De façon à assurer une parfaite indépendance, et bien que cela aurait été possible avec le calculateur utilisé, un programme ne peut accéder directement aux données d'un autre programme.

La seule possibilité d'échange d'information consiste à faire appel au superviseur, qui gère une zone de la mémoire affectée spécialement à cet usage par des mécanismes de lecture/écriture dans des fichiers.

Un programme est entièrement autonome : lorsqu'il est actif, il doit gérer l'ensemble des ressources du calculateur (coupleurs, interruptions) et du système (équipements). Les commutations de programme sont assurées par le superviseur.



La structure interne d'un programme reste celle des applications décrites au chapitre précédent : il reste divisé en fonctions logicielles, modules et pièces.

La décomposition des différents programmes d'une même application peut conduire à la définition de fonctions logicielles identiques. Dans ce cas, celles-ci ne seront alors implantées qu'une seule fois dans la mémoire du calculateur.

Du point de vue de l'écriture du logiciel, le programme sera caractérisé par :

- Un certain nombre de pièces en langage source qui lui sont spécifiques, contenant essentiellement le code de haut niveau pour l'exécution (description des processus, gestion des coupleurs, etc).

- La liste des fonctions logicielles permettant d'exécuter les différentes tâches qu'il doit assurer.

Le programme, étant entièrement autonome, est donc un élément de récupération absolu entre deux applications. Chacun pourra être validé séparément, et le seul contrôle à assurer pour une nouvelle application composée à partir de programmes précedemment existants et validés sera celui de la présence effective des programmes désirés dans la mémoire du calculateur.

D'un point de vue pratique, il a été décidé de faire correspondre un programme à chaque configuration d'emports définie par le Système de Navigation et d'Armements, c'est-à-dire à chaque mission opérationnelle exécutable par l'avion.

5.2.2. Langage de description de modules

Les buts poursuivis sont d'améliorer la lisibilité du logiciel, et de supprimer le recours à un commun général pour implanter les données interface entre fonctions logicielles. Par ailleurs, nous tenions, comme nous l'avons écrit plus haut, à continuer à utiliser le même langage de programmation, le LTR.

Le langage de description de modules est inspiré des notions les plus récentes en langage de programmation. Sa syntaxe permet de définir des modules, en isolant deux parties nettement distinctes :

- l'interface du module, où sont décrits :

  - les données : sens (entrée ou sortie), type, format, implantation...

  - les points d'entrée accessibles de l'extérieur à l'exécution. La règle d'utilisation générale est qu'il y ait un seul point d'entrée par module. Cependant, la possibilité d'en définir plusieurs peut permettre de choisir à un niveau supérieur (celui du programme) entre deux traitements différents sur la même interface.

- Le corps du module, constitué par :

  - les données internes

  - le code du module, pour lequel la syntaxe est la même que celle du langage LTR. En pratique dans nos applications, ce code est un squelette appelant les différentes pièces, celles-ci étant compilées séparément.

Le préprocesseur de modules transforme du source écrit en langage de description de modules en un source compatible de la syntaxe LTR, qui est ainsi exploitable par la même chaîne de production que le reste du logiciel. Cette transformation peut être réalisée sans qu'il ait été nécessaire de modifier le compilateur LTR existant.

Enfin, nous sommes en train de développer un analyseur de modules, cet outil aura pour rôle de vérifier la cohérence des interfaces des modules au niveau d'un programme, et d'établir des listes de référence croisées des données. Le langage de description de module est en effet utilisé au cours de l'étape de conception globale du logiciel, et il est particulièrement intéressant de pouvoir contrôler dès cette étape la cohérence de la définition des interfaces.

5.2.3. Extension de la machine virtuelle du calculateur

L'objectif ici était d'arriver à une récupérabilité parfaite au niveau des pièces de logiciel, en s'affranchissant même du problème d'identité des noms symboliques des variables interface. Le seul moyen réel d'y parvenir est de ne concevoir ces pièces que comme des sous-programmes travaillant exclusivement sur des listes d'arguments. Cette méthode est moins performante que l'utilisation de communs. Cependant, il était admis de déplacer le point d'équilibre entre optimisation et adpatabilité du logiciel pour aller dans le sens d'une plus grande souplesse.

C'est pourquoi, nous avons adjoint à la machine virtuelle des calculateurs un mode d'adressage "paramètre", optimisant cette méthode de transmission d'arguments. Les instructions utilisant ce mode d'adressage restent sur 2 octets (le calculateur est une machine 16/32 bits), ce qui limite le taux d'expansion induit.

5.3. Evolutions sur le plan fonctionnel

Avoir une structure offrant des possibilités de réutilisation de parties de logiciel existant ne suffit pas. En effet, l'utilisateur désire récupérer une fonction de son avion, correspondant à une entité sur le plan opérationnel. Il est donc nécessaire que le réalisateur ait une bonne connaissance de cet aspect opérationnel. A l'inverse, le spécificateur doit adopter une certaine discipline, et prendre en compte la nature et la structure du logiciel existant avant de définir un nouveau système, pour décider en toute connaissance de cause de demander des évolutions. C'est pourquoi, il est primordial qu'un véritable dialogue s'établisse entre spécificateur et réalisateur.

La première étape a consisté à retenir l'utilisation d'un langage commun, pour décomposer le problème à traiter sous les deux aspects opérationnel et fonctionnel. Un langage graphique a été choisi. Il entraîne en effet une plus grande concision, et sa syntaxe est suffisamment simple pour qu'il soit compréhensible après une formation vraiment minime. De plus l'aspect visuel est à privilégier, à partir du moment où l'on désire travailler avec des non informaticiens.

Ce langage est d'abord utilisé pour aborder le problème sous l'aspect opérationnel. Il s'agissait en effet d'aller plus loin que le découpage traditionnel, dont le critère était généralement une tranche de temps, comprise entre une action du pilote (l'enclenchement d'un mode) et une autre (la désélection de ce mode). La décomposition a pour but, au contraire, de faire apparaître des entités opérationnelles, qui réalisées en parallèle, conduisent à obtenir un mode complet. Un des points importants à ce niveau est de séparer ce qui dépend du type de l'avion, par rapport à ce qui est caractéristique de la mission. Cela conduit donc à définir une véritable modularité sur le plan opérationnel, ce qui est en fait une condition impérative pour espérer obtenir une modularité du logiciel. Cette étape est du ressort du spécificateur du logiciel.

La deuxième étape consiste à réaliser la décomposition fonctionnelle du problème avec le même langage. Les critères étant différents, cette décomposition ne sera pas la même que précédemment. La correspondance entre chaque élément de la décomposition opérationnelle et les éléments de la décomposition fonctionnelle, ainsi que la correspondance inverse, sont alors établies.

Cela permet donc au spécificateur comme au réalisateur de juger de l'adéquation de la décomposition fonctionnelle aux problèmes de l'utilisateur (moins un élément opérationnel sera éclaté entre différents éléments fonctionnels, meilleure sera la décomposition), et de déterminer les corrections nécessaires avant de commencer l'écriture du logiciel.

Cette approche permet de définir des entités fonctionnelles, donc par la suite des entités de logiciel, dont les frontières correspondent à des notions opérationnelles. L'étape suivante consiste à standardiser ces entités, leur définissant un rôle et des interfaces faisant au maximum abstraction de l'application dans le contexte de laquelle elles sont définies. Cette standardisation ne peut se faire que par coopération entre spécificateur et réalisateur, car elle doit prendre en compte aussi bien les évolutions prévisibles ou envisageables des systèmes, que les contraintes de réalisation. Elle peut s'accompsgner de la définition de paramètres de réglage de la fonction, permettant de l'adapter à des cas particuliers.

Cette approche nous a conduit à modifier certaines solutions (pas toutes, heureusement !) adoptées précédemment. L'effort a surtout porté sur les traitements liés aux équipements multimodes (viseurs, postes de commande), et ceci aussi bien sur le plan opérationnel que sur le plan fonctionnel.

Elle a en outre l'énorme avantage de permettre au maître d'oeuvre du système de mieux connaître la structure du logiciel. Une conséquence directe en est la possibilité d'en tenir compte pour la conduite des essais d'intégration du Système : elle permet d'appréhender le logiciel comme plusieurs entités travaillant ensemble, et non comme une seule. Il devient dès lors possible de recourir à une approche sélective des test à repasser en cas de modification d'une partie du logiciel. Cela va amener les équipes d'essais à contrôler systématiquement des informations internes du calculateur, et non plus simplement des interfaces entre celui-ci et les autres équipements du système.

6. CONCLUSION ET PERSPECTIVES

La modularité n'est qu'un des aspects de la production d'un logiciel. C'est cependant un élément primordial dans la recherche d'un abaissement du prix de revient en permettant la réutilisation d'éléments logiciels existants et validés. C'est à notre avis le second service qu'un réalisateur puisse rendre à un utilisateur, le premier restant de lui fournir un logiciel qui fonctionne correctement.

Les différents outils et méthodes décrits dans ce document sont actuellement utilisés sur un logiciel en cours de développement. Il faut donc attendre l'épreuve du temps pour voir si tous les objectifs fixés seront tenus. Notre expérience passée nous permet cependant d'espérer un taux de réussite significatif. En particulier, nous attendons beaucoup de renforcement des dialogues entre utilisateur et réalisateur.

Notre effort a surtout porté sur les possibilités de récupération de code proprement dit. Ca n'est en fait qu'un des aspects de la production du logiciel, les autres étant la documentation et les fichiers de validation. Nous avons également mis en place un certain nombre de moyens, essentiellement des outils universels graphiques, de traitement de textes, et d'archivages. Il ne s'agit pourtant que de solutions partielles, forcément limitées.

La solution réelle viendra avec l'utilisation d'un "Atelier Intégré de Génie Logiciel" prenant en compte les aspects de la production de logiciel, depuis les Spécifications jusqu'au suivi en exploitation. En particulier, en facilitant la mise en oeuvre de langages de spécifications, il devrait permettre une amélioration de la qualité de celles-ci, ce qui ne pourra que renforcer leur stabilité.

DISCUSSION

K.F.Boecking, Ge

You presented a modular software system and talked about software validation. What is the exact way, especially in a modular system, you make sure that the algorithms do what you hope they are doing? Do you test all input conditions?

Réponse d'Auteur

Notre méthodologie de développement du logiciel prévoit plusieurs niveaux de test. En particulier les tests unitaires permettent de contrôler le fonctionnement de chaque pièce de logiciel prise séparément, et les "tests fonctionnels" permettent de contrôler le fonctionnement de chaque fonction logicielle. Ces tests, réalisés en usine, concernent le logiciel et lui seul. C'est pourquoi ils peuvent être très profonds, et une très grande variété de jeux d'essais peuvent être passés, notamment grâce à une "baie de validation de logiciel" qui nous permet de faire fonctionner le logiciel dans des conditions réelles.

Le logiciel est ensuite pris en main, au même titre que les autres équipements, par le maître d'oeuvre du système qui conduit l'intégration de ces différents équipements par des essais en vol. Un des interêts de notre approche est que les équipes chargées de cette intégration vont pouvoir considérer le logiciel comme plusieurs boites noires, et non plus comme une seule. En analysant des données internes du logiciel, elles pourront donc valider séparément les entités composant celui-ci.

W.McKinlay, UK

I am interested in the first part of the design process involving a dialogue between the operator and the design team. Is this accomplished using a formal design language? At what level is it mechanized using computers as opposed to manually or by discussion?

Réponse d'Auteur

Comme nous l'avons précisé au cours de l'exposé, un même langage de conception graphique est utilisé par le spécificateur du logiciel pour réaliser une décomposition sous l'aspect opérationnel, et par le réalisateur pour une décomposition sous l'aspect fonctionnel. La décomposition opérationnelle fait partie intégrante des Spécifications Opérationnelles du logiciel, constituant le cahier des charges, pour la réalisation du celui-ci.

Par contre, ce langage n'est pas utilisé par la rédaction des spécifications globales du Système de Navigation et d'Armements, et n'est donc pas utilisé pour le dialogue utilisateur-spécificateur.

INCREASING SIGNIFICANCE OF ELECTROMAGNETIC EFFECTS IN MODERN AIRCRAFT DEVELOPMENT

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SUMMARY

Due to the use of new materials, the enlargement of the electromagnetic environment, the increasing susceptibility of electronic components and the rising dependence on satisfactorily functioning electronics, greater attention must be paid to electromagnetic effects in modern aircraft development.

The increase in the scope of problems in comparison with the past and the possibilities which can be recommended for their solution are presented in this paper.

1. INTRODUCTION

The following aircraft structures with their respective era-oriented equipment, environment and significane of the electronic components for the aircraft are taken into consideration in this context:

- pure metal structure (aluminum)
- mixed structure (aluminum structure with avionic access doors or panels made of glass reinforced plastics = GRP or carbon fiber composite = CFC; if larger parts are made of e.g. CFC, such a part shall be considered as a CFC-structure
- CFC-structures.

2. SURVEY OF THE ELECTROMAGNETIC EFFECTS CONSIDERED

In order that an aircraft may fulfil its tasks reliably and satisfactorily, the following problems with reference to the electromagnetic effects must be solved (Fig. 1):

- internal electromagnetic compatibility, i.e. the equipment in the aircraft must not interfere with itself.
- external electromagnetic compatibility, i.e. satisfactory functioning must be ensured even in a certain radiation environment.
- lightning protection
  Merely the influence on the electrical system is considered at this point. Moreover, only a direct hit is taken into account, since this also covers the effects of a nearby stroke of lightning.
- hardening with respect to the nuclear electromagnetic pulse (NEMP).

Electrostatics are neglected here, since the problems occurring in this connection can be solved relatively easily irrespective of the method of construction. - Consideration of internal compatibility is restricted to the most important effect in conjunction with the airframe construction, namely on the coupling between antennas and internal electrical system/electronics. The internal compatibility can thus be dealt with together with the external compatiblity in the following section.

3. PRINCIPLE UNDERLYING INTERFERENCE WITH THE EQUIPMENT AND ASSURANCE OF COMPATIBILITY

Interference takes place basically as shown in Fig. 2.

Interference signals are coupled into the system along the relevant paths from the interference source. They spread throughout the system and reach the equipment in the form of fields and conductive interferences. It depends on the susceptibility of the equipment in comparison with the levels of the incoming interferences as to whether (permanent) destruction, (temporary) interference or no effect at all occur.

Possible interference sources shown in Fig. 2 are considered: EMC, lightning stroke and NEMP.

The compatibility of the equipment is ensured by being protected in accordance with the incoming levels and their significance for the system (whereby these incoming levels must be kept as low as possible through protective measures at system level). Basically, equipment critical with respect to safety is protected against lightning, NEMP and EMC effects, equipment critical with respect to the mission against NEMP and EMC, and all other equipment solely against EMC. - A safety margin of 20 dB is required in connection with EMC for equipment critical with respect to safety, and of only 6 dB for all other equipment.

4. DANGER TO THE ELECTRICAL SYSTEM/ELECTRONICS AS A FUNCTION OF TECHNICAL DEVELOPMENT IN AIRCRAFT CONSTRUCTION

4.1 General

The airframe structures (metal, mixed, CFC) listed in Section 1 correspond to advanced developments both in terms of technology and of time. Combining these aircraft types with the pertinent era-oriented electromagnetic environment and electrical system/ electronics permits deriving qualitative statements concerning a change of the danger entailed by the electromagnetic effects as a function of time or of technical developments, respectively. Basically, one may proceed along the lines of Fig. 3, whereby changes in terms of time must be taken into account.

4.2 Development of the Electromagnetic Environment

EMC, lightning stroke and NEMP are considered here.

As far as EMC is concerned, a gradual increase in the electromagnetic environment takes place, due to higher transmitter powers, more frequent transmitters and an expansion of the frequency range. A jump of at least 3 dB between the aircraft types under consideration can be assumed.

As a natural phenomenon, the lightning stroke is of course constant. The threat model, however, will perhaps have to be adapted in future to meet new requirements. Faster semiconductors make it necessary to take into consideration faster lightning. In the following, however, lightning will still be assumed to be constant for all three types of aircraft.

At least in the FRG, NEMP has only recently entered the scene as a threat parameter. For new developments, this could be related to the aircraft types, approximately as of the mixed structure. Since, however, NEMP is of general interest in connection with subsequent hardenings, the nuclear pulse is considered for all aircraft types. For this reason, Fig. 3 is taken as a basis as the electromagnetic environment in conjunction with the aircraft types.

Fig. 4 provides an overview as to which frequency range is involved with EMC, lightning and NEMP (powers/energies; approx. 10 - 90 % for the pulse-shaped signals).

4.3 Coupling In Via the Airframes

The fields coupled in and the interference signals on lines, which again depend on the fields, are of interest.

4.3.1 Fields Coupled In

Basically, a differentiation can be made between two types of coupling in , namely:

- the direct coupling in of the external fields (of importance in connection with EMC and NEMP).
- the coupling in through currents on the structure (of importance in the case of a direct lightning hit and the resonant currents occurring due to NEMP).

A) <u>Coupling In of the External Fields</u>

Fig. 5 shows the attenuation curve for a typical aluminum and CFC structure, respectively.

In the lower frequency range, the curve applies to magnetic fields (electrical fields are suppressed satisfactorily caused by high reflection loss in the case of poor conductive materials, such as CFC, too).

The attenuation is limited locally as a result of apertures which are leaky in the electrical sense (e.g. access doors to avionics). A mean value of 40 dB is assumed, which can be reached without any great efforts.

In the upper frequency range, the attenuation is decreased due to aircraft resonances and due to resonance effects of the leaky apertures.

Comparing the curves shows the following differences between the aluminum and CFC structures:

a) EMC

Degradations amounting to up to 30 dB at frequencies below some 100 KHz for the CFC structure. In the case of a closed structure (optimum shielding), the difference would be present at higher frequencies, too.

b) NEMP

As far as the direct coupling in of the fields is concerned, when assuming the 40 dB limit for an airframe sealed involving average effort, it is almost negligible as to whether the latter is made of CFC or of aluminium. - The difference for closed structures would be considerable (Fig. 6: 90 dB for Al in comparison with 21 dB for CFC).

Aircraft with mixed structures behave similarly to metal aircraft. However, they certainly feature greater local field intensity increases at higher frequencies, too, when GRP is used as the door material (even than with CFC).

B) Coupling In Fields through Currents on the Structure

This type of coupling in is of importance for the direct lightning hit and for NEMP. The latter can cause resonance currents outside on the structure of up to some KA at frequencies from 10 MHz up to some 10 MHz (small aircraft!).

The fields generated can be estimated with the aid of the simple model shown in Fig. 7. The fuselage is approximated by means of a cylinder featuring a constant wall thickness and an aperture.

The following fields are generated:

a) An E-field depending on the transfer impedance and on the current flowing outside on the structure.

b) Magnetic fields near the aperture depending on the local current distribution, and decreasing inside with the cubic number.

Fig. 8 illustrates the typical transfer impedance of an aircraft fuselage made of aluminum and CFC.

When CFC is used, fields of about 1500 V/m (with Al merely: 0.2 V/m) are yielded everywhere in the aircraft fuselage for the current of the customarily used standard lightning of 200 KA. In the case of NEMP, fields of approx. 10 V/m (CFC) or 10^{-10} V/m (Al), respectively, are generated. - An aircraft with a mixed structure should be considered in this case like a metal aircraft.

Large local field intensities greater than the levels indicated above may occur due to transfer resistances between airframe parts in the case of the metal as well as the CFC structure. Fig. 9 provides an idea of this. In the event of lightning, voltage differences amounting to about 20 V are yielded with an aluminium structure and to approx. 0.2 V with NEMP. Values of 4000 V (decrease by flash-overs) or 40 V, respectively, can be generated by the CFC airframe.

In the case of fields coupled in through the aperture, an attenuation of 40dB is assumed in accordance with Fig. 5. H-fields of approx. 500 A/m (lightning) or of 5 A/m (NEMP), respectively, are then yielded for Al as well as CFC structures (equal current distribution) for a fuselage diameter of about 1.5 m. - Mixed structures behave similarly to metal or CFC structures when CFC is used to cover the aperture. Local field increases occur in the case of GRP.
Somewhat different conditions arise comparing the types of structures upon taking into consideration that, in general, metallic longitudinal conductors (e.g. frames, tubes) are used inside aircraft. This is not significant for metal airframes.

With CFC structures, however, part of the currents flowing externally is concentrated on these internal conductors. As a result, additional magnetic fields occur everywhere in the aircraft.

Fig. 10 gives an idea of which field intensities may occur. A metal conductor should be located in longitudinal direction in the aircraft fuselage, featuring a cross section of 500 mm^2 and an inductivity of approx. 0.2 uH/m.

After a lightning stroke, currents up to 30 KA flow on the internal conductor in CFC structures. Even at a distance of 30 cm, these generate fields of up to 15 KA/m. The corresponding levels for aluminum structures are approx. 5 A and 2-3 A/m.

In the case of NEMP, the corresponding levels are small compared with the fields intensities coupled in via the apertures.

Particularly with CFC structures, the ratios become even more unfavourable when a joint between the airframe parts is bridged by the internal conductor (Fig. 9).

C) Comparison Between Coupling In of Fields with Respect to the Different Types of Airframes

Fig. 11 serves to compare the different types of aiframes with respect to the aluminium airframe.

A distinction is made between local couplings in and couplings in which are generally effected over the entire airframe.

It is shown that the mixed structure basically behaves like the metal airframe, but that local field intensity increases may occur.

This applies especially to the use of GRP avionic doors or panels.

Relatively large differences arise with CFC, which affect the entire interior of the airframe.

For EMC the differences in the lower frequency range amount from 0-30 dB to some 100 KHz.

For lightning, the differences would amount to 70 dB, taking the closed structures into account. Upon consideration of the couplings in through apertures, the differences are reduced to approx. 30 dB.

With NEMP, differences amounting to 60 dB (closed structure) or approx. 10-20 dB, respectively (apertures taken into consideration), must be anticipated.

4.3.2 Coupling into Cables

The interference signals induced in the cables depend on the existing fields (Section 4.3.1) and on the conductive coupled in signals.

The differences with respect to conducting coupling among the various types of airframes can be estimated approximately by means of the model shown in Fig. 10.

A conductor (e.g. cable shield), which may feature an inductivity of 1 uH per m, is assumed in a cylinder characteristic of the airframe under consideration. The ratio between the current flowing externally over the airframe and the current on the internal conductor can be taken as a criterion for the conductive coupling.

This is shown for a typical closed CFC and Al structure in Fig. 12. The relatively high levels which are coupled in the lightning range with CFC structures as well as the extreme differences between CFC and Al airframes are illustrated. Upon considering practical aspects, for instance the presence of a joint, the differences decrease. However, they still amount to over 40 dB (dashed curves in Fig. 12). This value is almost constant in the frequency range observed, i.e. it applies basically to EMC, lightning and NEMP.

Mixed structures behave similarly to metal structures (slight increase, since the impedance between the airframe parts is in certain circumstances larger over the circumference.

4.3.3 Comparison Between Coupling In with Respect to the Airframes Under Consideration.

The fields coupled in must be considered at this point in conjunction with the signals induced in the cables.

If the results shown in Fig. 11 and 12 are taken as a basis, approximately the following degradations can be estimated for the CFC structure in comparison with the metal structure:

- EMC:
  up to 30 dB in the lower frequency range; no degradation in the remaining range.

- effect of lightning:
  about 40 dB

- NEMP:
  about 20 dB.

Mixed structures (use of GRP!) lie between the CFC and the metal structures. Since they differ from the latter above all due to locally limited field intensity increases they shall be classified nearer to the metal airframes. A difference of about 5 dB is assumed.

The numerical values estimated above certainly depend very considerably on the respective aircraft configurations. However, they do provide some reference values for the orders of magnitude to be anticipated.

4.4 Susceptibility of Electronic Components

The following were used in succession as typical components in aircraft electronics: the tube, the transistor and the integrated circuit.

The destructive and interfering energies for these components are plotted in Fig. 13. It is evident that up to now the susceptibility has continued to increase with the advance of technical developments. A difference of around 40 dB exists between tube and transistor, between transistor and IC a difference of about 20 dB.

There are links in terms of time between the components shown in Fig. 13 and the aircraft structures under consideration.

Although tubes will still be met within modern CFC aircraft and integrated circuits are already being applied in metal aircraft, certain focal points of application will still remain.

The following can be stated:

- metal structures:
  tubes, transistors

- mixed structures:
  transistors, IC's

- CFC structures:
  IC's.

4.5 Danger to the Equipment in the different Aircraft Structures

It is possible to make a statement on the danger to the equipment by comparing the electromagnetic environment coupled in with the existing susceptibilities. Fig. 14 provides such an illustration for the aircraft structure under consideration.

The interferences coupled in are broken down respectively into EMC, lightning and NEMP. The explanations in Section 4.3 were taken as a basis for coupling in, and Fig. 3 for the development of the electromagnetic environment.

Fig. 14 shows the following:

- In general, the problems which are to be solved in connection with the "electromagnetic effects" increase tremendously as time goes on and technology advances.

- Problems concerning lightning protection become particularly extensive. In comparison with metal aircraft featuring tubes, they increase by the factor of approx. 10^{10} in the case of modern CFC aircraft featuring IC's. - The same applies to a somewhat lesser extent to NEMP.

- The problem relating to EMC appear to increase less strongly, with the exception of the lower frequency range, which is not usually of any great significance. What must be taken into consideration in this context, however, is that aircraft are becoming dependend to an ever greater degree on the electronics, i.e. more and more equipment is becoming critical with respect to safety. This, however, requires safety margins of 20 dB instead of 6 dB. All in all, differences of more than 20 dB are the case here (comparing metal with CFC aircraft).

- The transition from previously used metal and mixed structures to CFC airframes entails problems relating to lightning protection, EMC as well as NEMP hardening which are almost as extensive as those encountered earlier with metal aircraft upon transition from tube to semiconductor technology.

5. POSSIBLE SOLUTION TO THE PROBLEMS

The details given in the previous section showed that considerable problems remain to be solved in connection with lightning protection, NEMP hardening and EMC, in particular as far as the transition to CFC construction is concerned. This, however, is just the step which is currently being undertaken in aircraft development. The existing manuals and specifications can only be used to solve the problems to a limited extent, since the know-how defined therein is based on metal aircraft. Some thoughts concerning possible additional requirements and changes are compiled in the following section. However, a great number of experimental and theoretical investigations must be carried out before reliable and optimum solutions can be drawn up. However, the problems can be solved.

Fig. 15 provides a survey of the measures which appear to be necessary. They extend from the airframe level over the cabling and ground concept up to more stringent equipment requirements and additional tests at system level.

A) Airframe/Structure

This must be designed so as to be as leak-proof as possible from the electrical point of view, in order to achieve on the one hand good shielding attenuation and on the other hand low voltage drops. The electrical sealing of access doors etc. as well as the creation of low-resistance transfer resistances between airframe parts are of particular interest.

Metallizing CFC structural parts does appear helpful but not absolutely necessary for electrical reasons. If this is necessitated for lightning protection, for instance, it should be incorporated in the shielding concept.

B) Cabling and Grounding Concept

In addition to the greater attention to be paid to the customary EMC guidelines, the following items are of especial interest:

a) absolute both-end grounding of the cable shields

b) avoidance at all costs of pig-tail grounding. In particular with NEMP (resonance currents on the aircraft structure!) as well as with EMC, degradations amounting up to 40 dB can be expected for average cable lengths and single braid shields (Fig. 16). This means that the 10^4-fold interference power is coupled in.

c) control of other possible leakage places in the shielded circuit. If the shielding has been grounded properly, other electrical leakage places become increasingly predominant. This applies especially in connection with lightning protection and NEMP hardening. Transfer resistances between connectors, connectors and cases and case sections are of importance (Fig. 17).

d) Routing of the Cables

In view of the increasing effect of external interferences, the cabling concept must in certain circumstances be conceived a new (Fig. 18). The internal compatibility was of primary interest for metal aircraft. This meant laying the cables of the different EMC categories as far apart as possible (to prevent cross coupling!). In the case of pure CFC structures, the magnetic fields caused by external sources of interference (lightning, NEMP) could certainly be of greater significance. Laying all three EMC categories in one bundle of cables would then be more favourable (prevention of loops!).

e) Grounding Concept

The grounding concept is of great importance when interference signals are coupled in (Fig. 19). This applies in particular to the low-frequency range, i.e. in connection with lightning protection. Depending on the grounding, the differences may amount to 100 dB. Greater control of input filters and capacities appears necessary in this context, too, since the ground conditions can also be impaired by the latter.

C) Equipment

It is important to know whether, for instance, more stringent requirements should be stipulated for each piece of equipment or whether, for instance, the introduction of shielded compartments is preferable (Fig. 20). This would probably permit the use of electronics tested according to previously customary standards. One problem in connection with the equipment might in certain circumstances relate to the coupling of circuits via the inside of the equipment, e.g. between non-critical circuits on which relatively high interference levels are permissible, and ones which are critical with respect to safety (Fig. 21).

D) Use of new techniques

Especially in connection with CFC structures the use of optical links seems to be very helpful. Almost all EMC-, lightning- and NEMP-problems can be avoided.

E) Additional Tests at System Level

These are necessary, since compatibility with the interference effects.

- will be ensured more and more by means of measures at system level
- any interferences which may occur jeopardize the safety of the aircraft to an incrasing degree.

Comprehensive test set-ups have already been developed for NEMP hardening. This is just at the starting point as far as lightning protection is concerned. This is limited with regard to EMC above all to verification of the internal compatibility. Compatibility with the environment is hardly taken into account. For this reason, the introduction of appropriate requirements and standardised procedures appears to be necessary above all for lightning protection and external EMC.

6. Conclusion

The above statements have shown that, as technical progress is made, the problems concerning electromagnetic effects in aircraft construction become increasingly difficult to solve. This is primarily due to the increasing susceptibility of the electronic components and to the more unfavourable coupling-in conditions with modern structures. This has become a particularly large step upon the introduction of CFC construction. In general it can be said that far more care must be paid to obeserving the appropriate design guidelines in order to be able to solve the pertinent problems. In part, however, some thought must be paid as to whether previously applicable principles should be subject to revision as well. However, the problems can be solved.

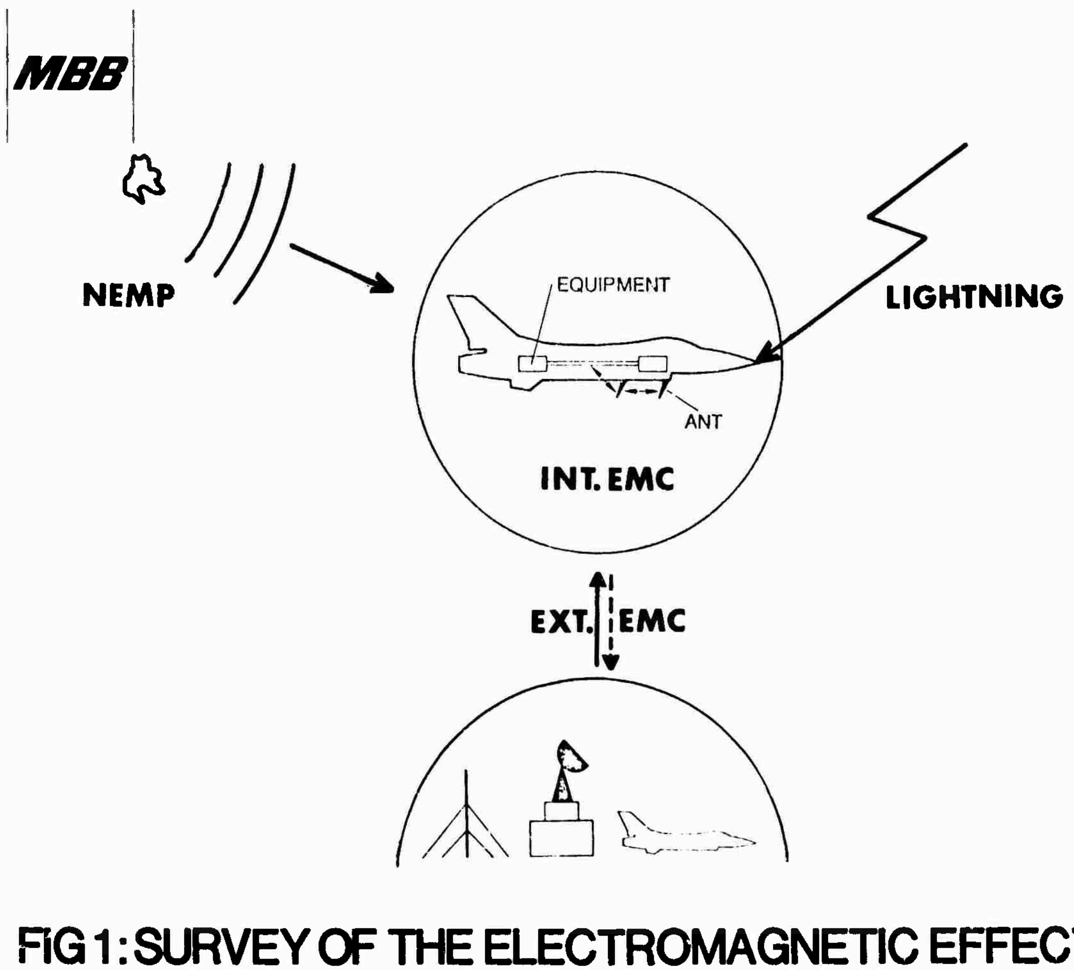

FIG 1: SURVEY OF THE ELECTROMAGNETIC EFFECTS

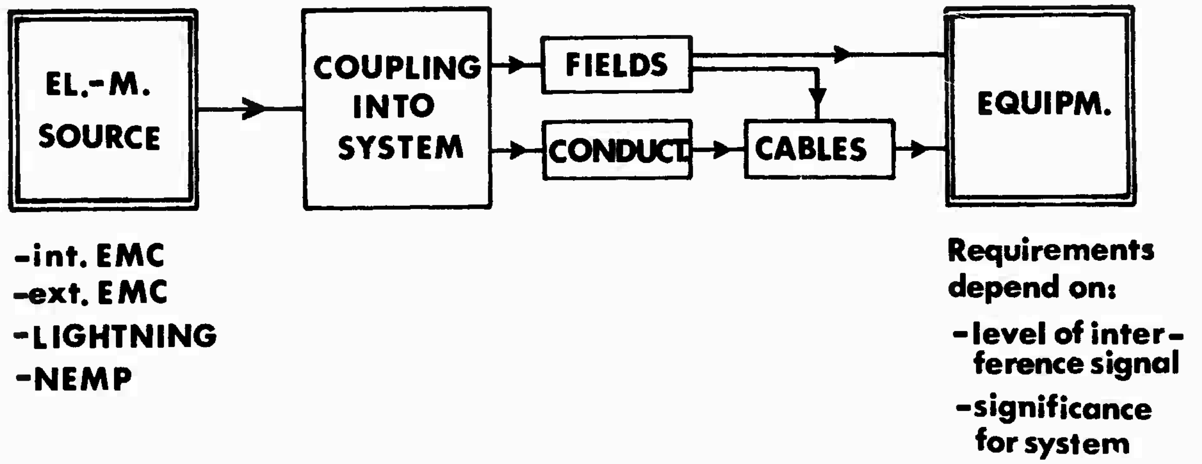

FIG 2: PRINCIPLE OF ELECTROMAGN. INTERFER. / DISTURBT.

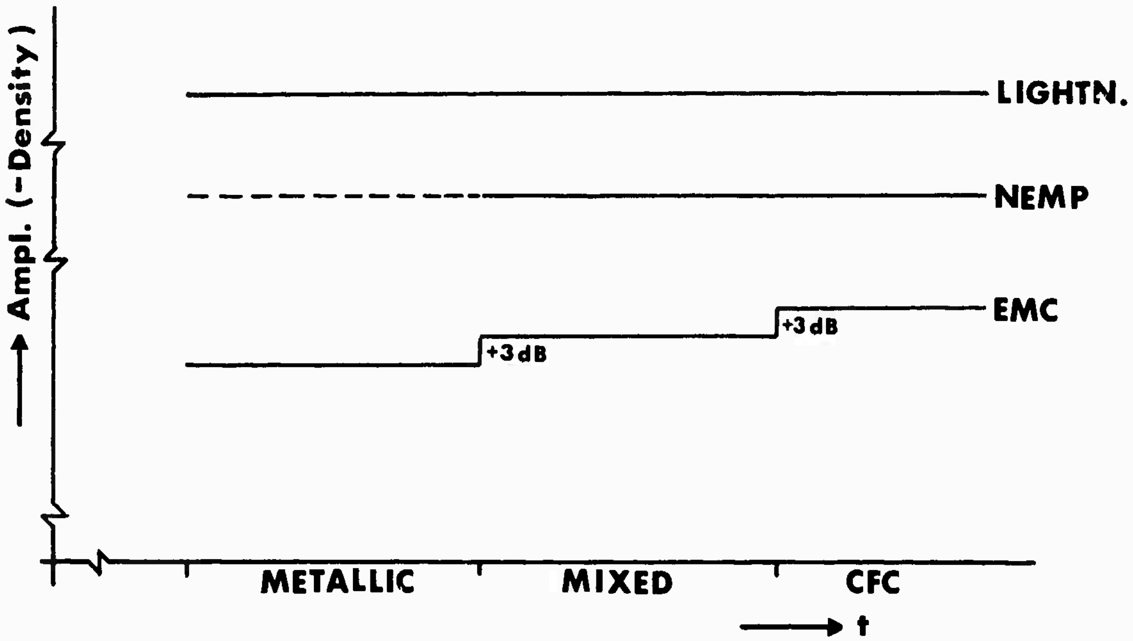

FIG 3: DEVELOPMENT OF ELECTROMAGNETIC
ENVIRONMENT

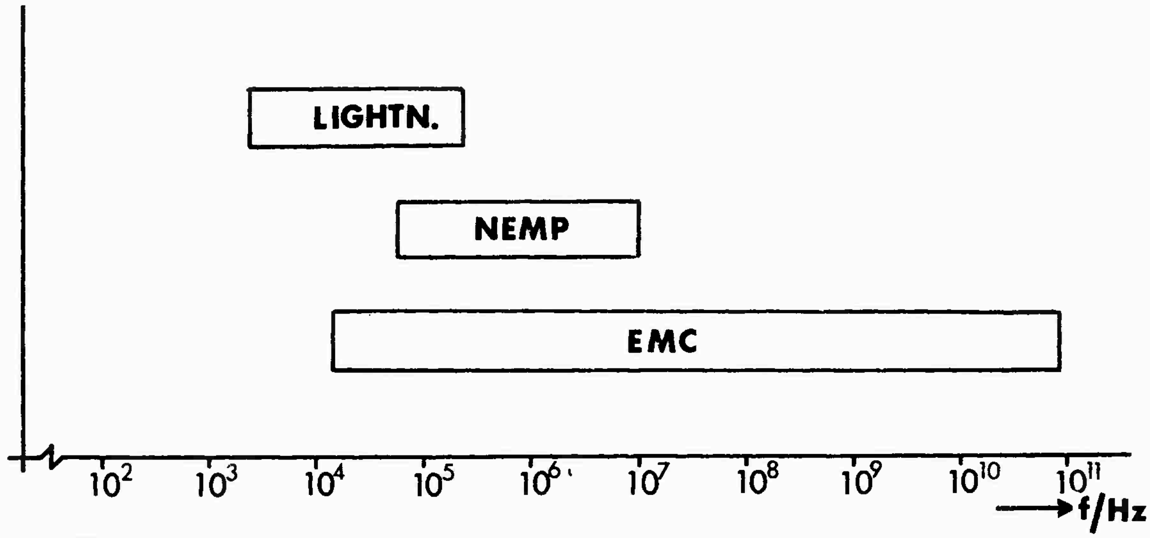

FIG 4 : MAIN FREQUENCY RANGES OF THE ELECTROMAGNETIC EFFECTS

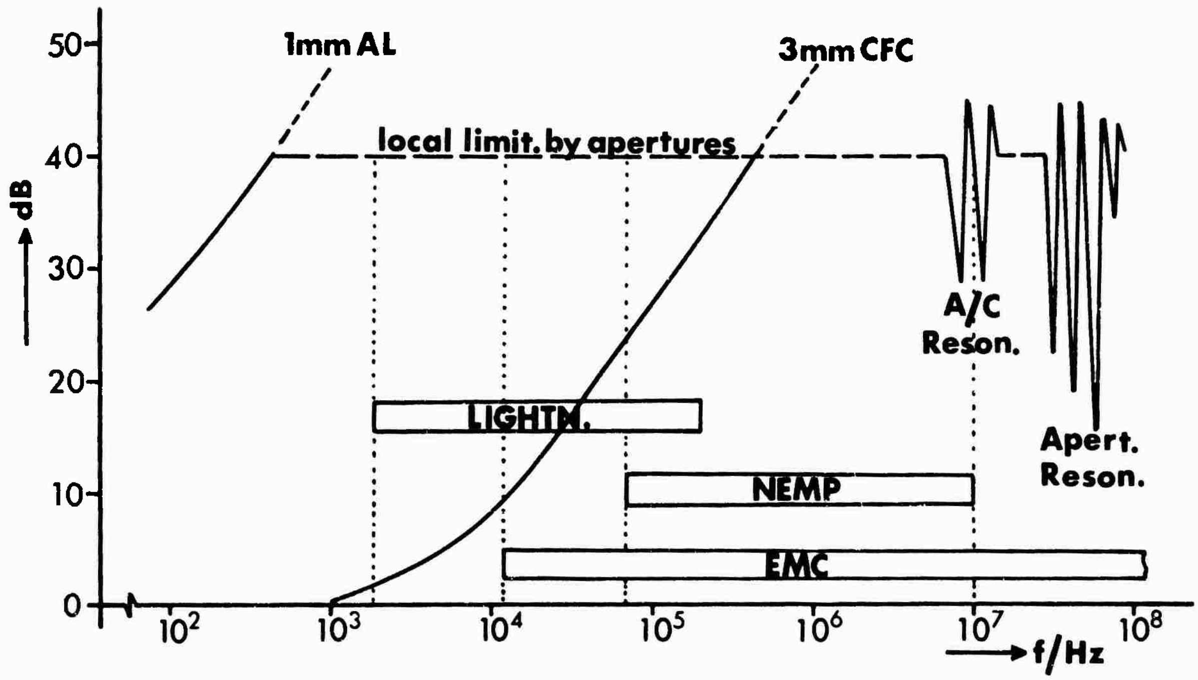

FIG 5 : SHIELDING OF TYPICAL STRUCTURES (H-FIELD)

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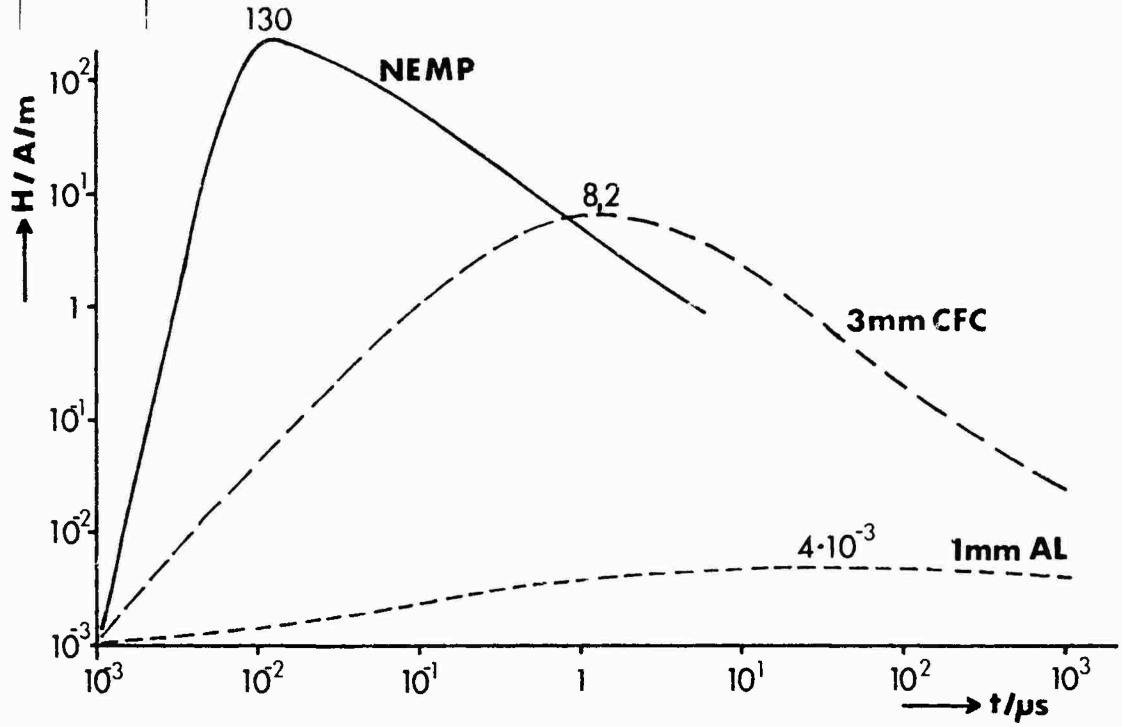

FIG 6: NEMP-SIGNALS COUPLED INTO CLOSED STRUCTURES

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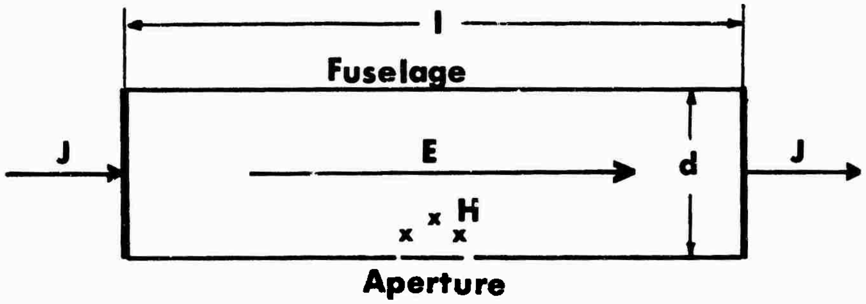

$$E = \frac{Z_t \cdot J}{l}$$

$$H = f(S)$$

$$S = \frac{J}{\pi \cdot d}$$

FIG 7: FIELDS IN FUSELAGE

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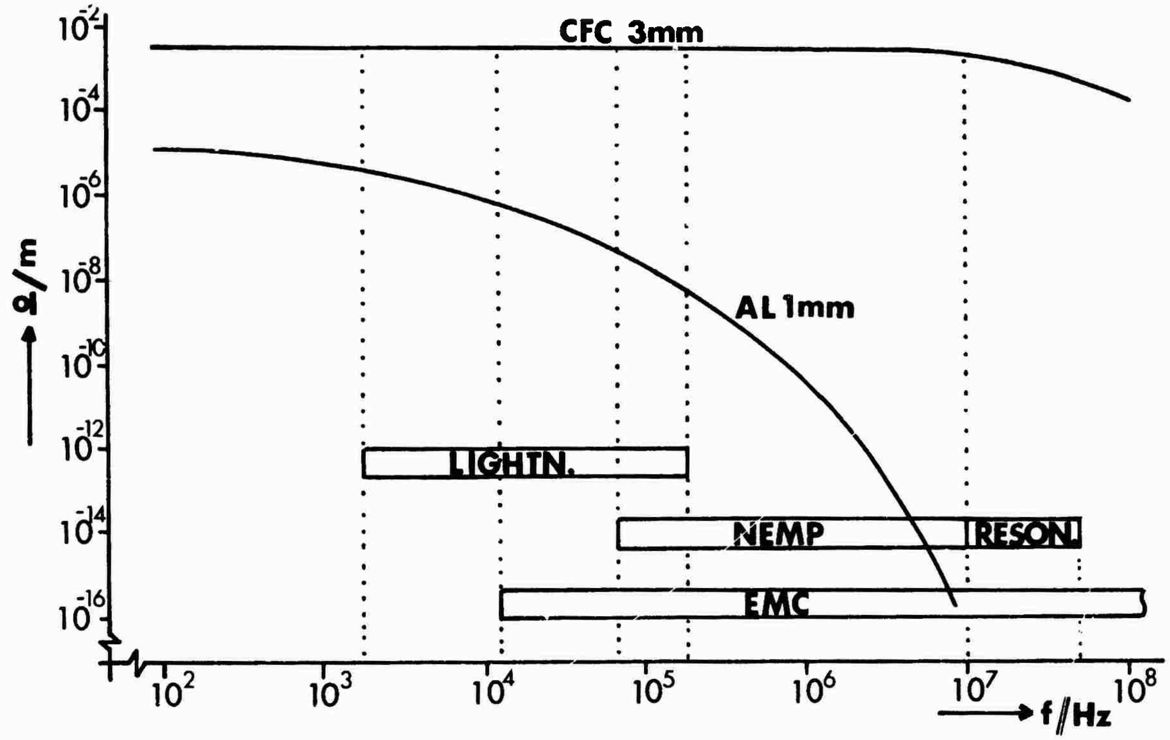

FIG 8 : TRANSFERIMPEDANCE OF TYPICAL FUSELAGES

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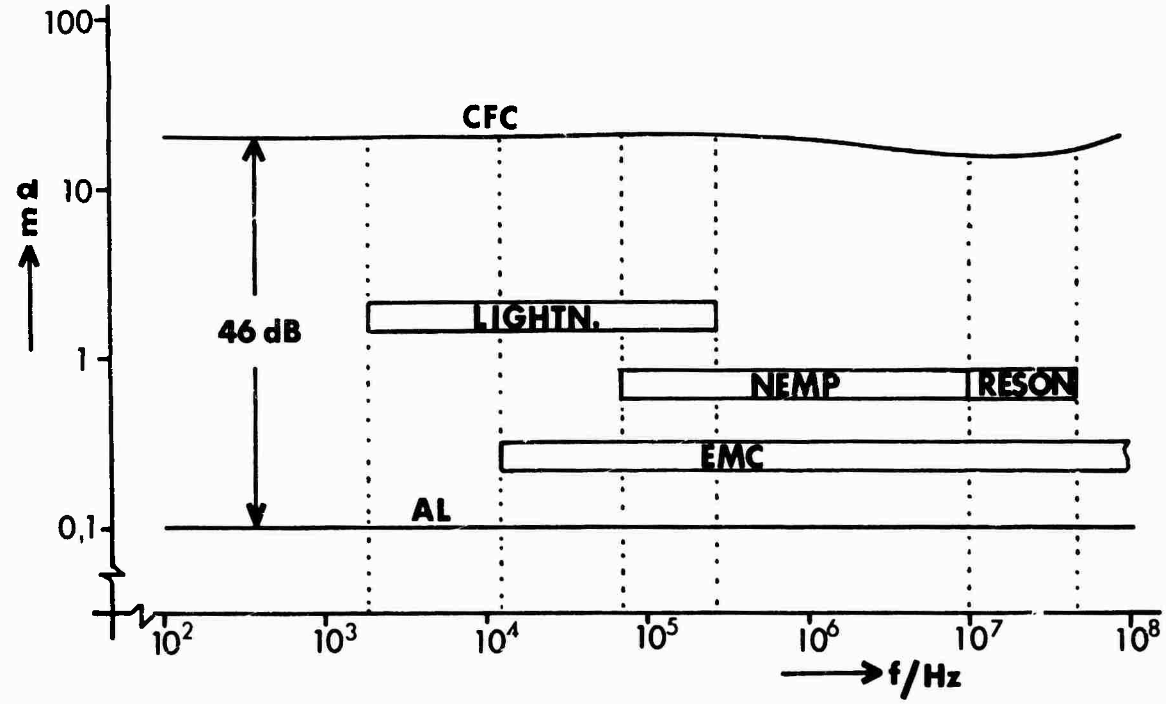

FIG 9 : IMPEDANCE OF TYPICAL JOINTS AROUND THE FUSELAGE

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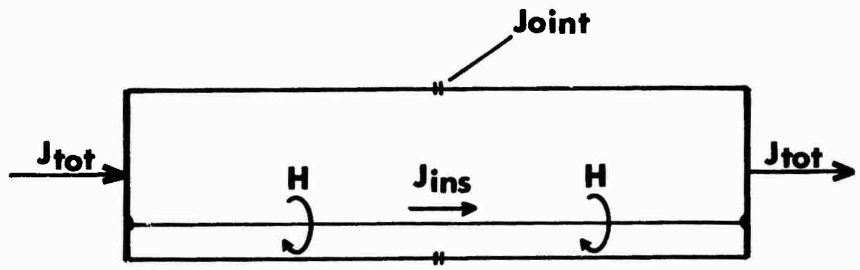

$$J_{ins} \approx J_{tot} \cdot \frac{Z_t}{R + wL}$$

$$H = \frac{J_{ins}}{2\pi \cdot r}$$

FIG 10: INSIDE CURRENTS AND INSIDE FIELDS

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		MET.	MIXED	CFC
EMC	overall	0 dB	0 dB	0-30 dB
	local	0	>0	0
LIGHTN.	overall	0	0	70^{x} (>30)^{xx}
	local	0	>0	0
NEMP	overall	0	0	60^{x} (≤16)^{xx}
	local	0	>0	0

related to: x overall level
xx local level

FIG 11: INSIDE FIELDS RELATED TO METALLIC STRUCTURE

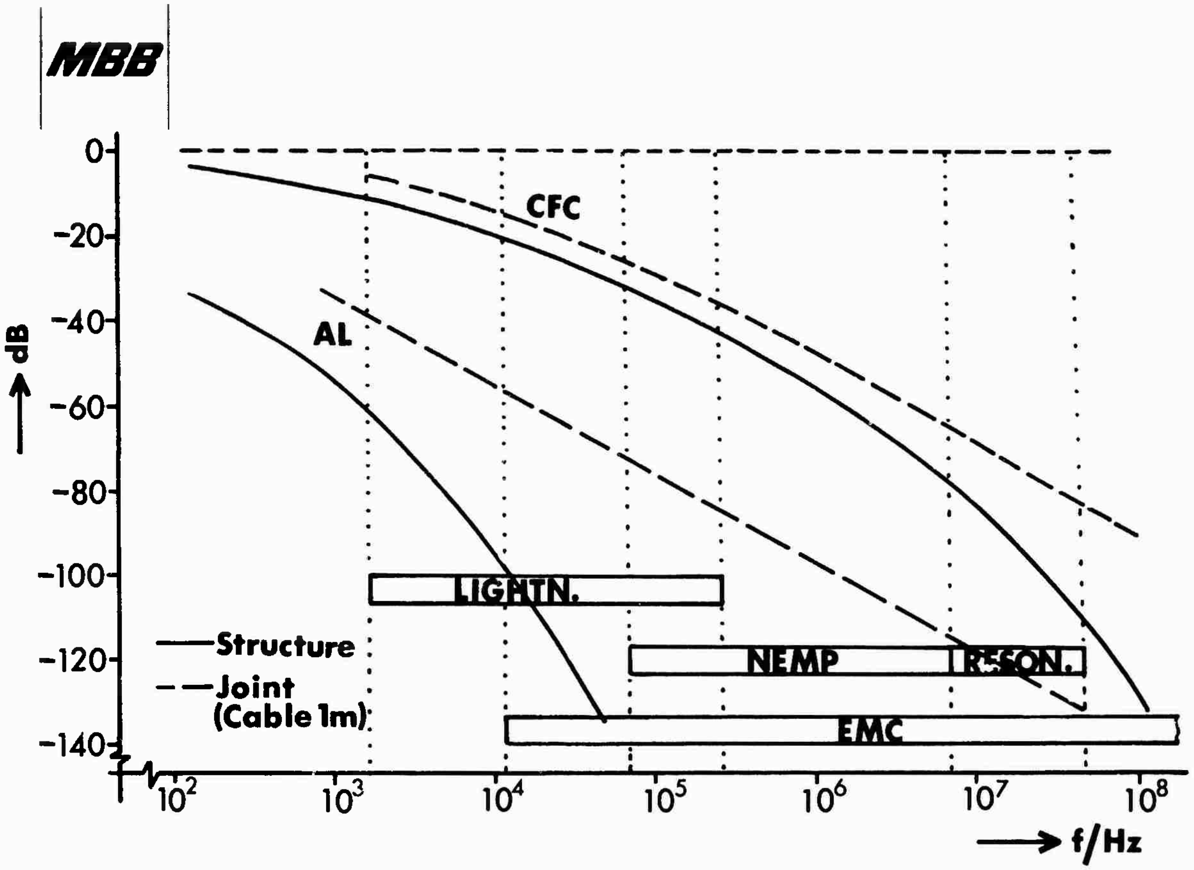

FIG 12: CONDUCTIVE COUPLING INTO CABLES

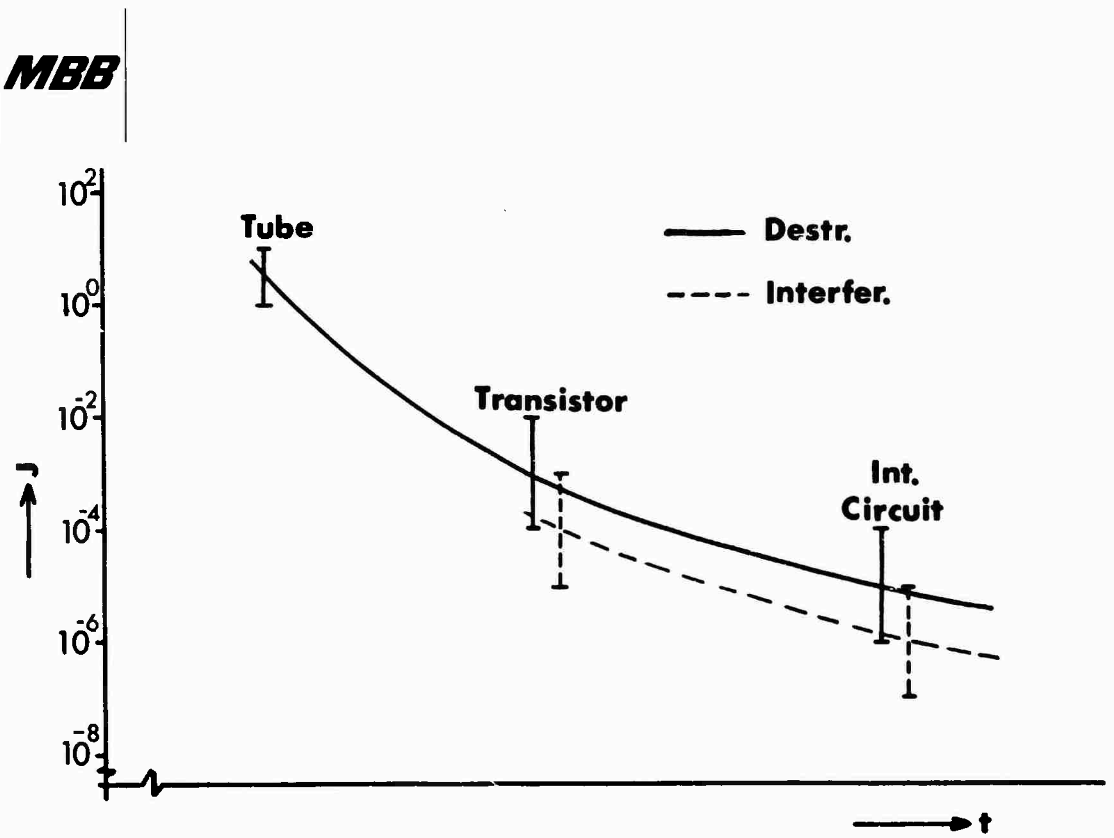

FIG 13: SUSCEPTIBILITY OF TYPICAL ELECTRONIC COMPONENTS

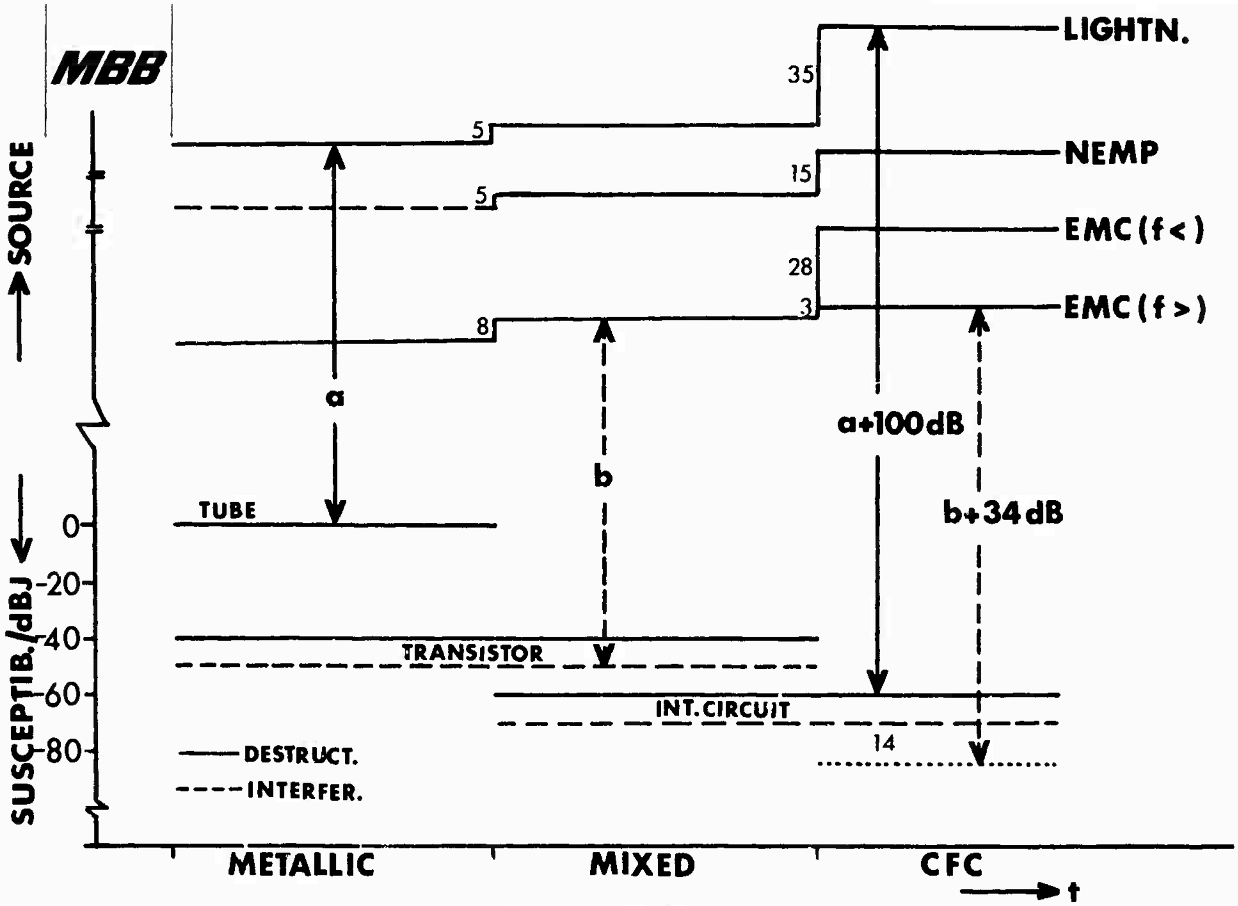

FIG 14: INCREASING DIFFERENCE BETW. COUPLED-IN SIGNALS AND EXISTING SUSCEPTIBILITIES

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BETTER INTEGRATION OF STRUCTURE INTO EMC-DESIGN

- GOOD SHIELDING
- LOW-RESIST. JOINTS

MORE CAREFUL CONTROL OF CABLING AND GROUNDING

USUAL EMC-DESIGN;OF SPECIAL INTEREST:

- BOTH END GROUNDING OF CABLE SHIELDS
- NO PIG-TAIL GROUNDING OF SHIELDS (FIG.16)
- CONTROL OF OTHER LEAKAGES IN THE SHIELDED CIRCUIT (FIG.17)
- OTHER CABLE ROUTING PHILOSOPHY? (FIG.18)
- CAREFUL GROUNDING CONCEPT! (FIG.19)

ADDITIONAL REQUIREMENTS ON EQUIPMENT LEVEL

- HIGHER REQUIREMENTS FOR EQUIPMENT OR INSTALLATION OF SHIELDED COMPARTMENTS?(FIG.20)
- CONTROL OF COUPLING VIA EQUIPMENT?(FIG.21)

ADDITIONAL TESTS ON SYSTEM LEVEL

- NEMP : IN USE
- LIGHTNING : IN BEGINNING
- EMC : INTERNAL EMC;NO STANDARD ENVIRONMENT TESTS

FIG 15: SURVEY OF IMPROVEMENTS

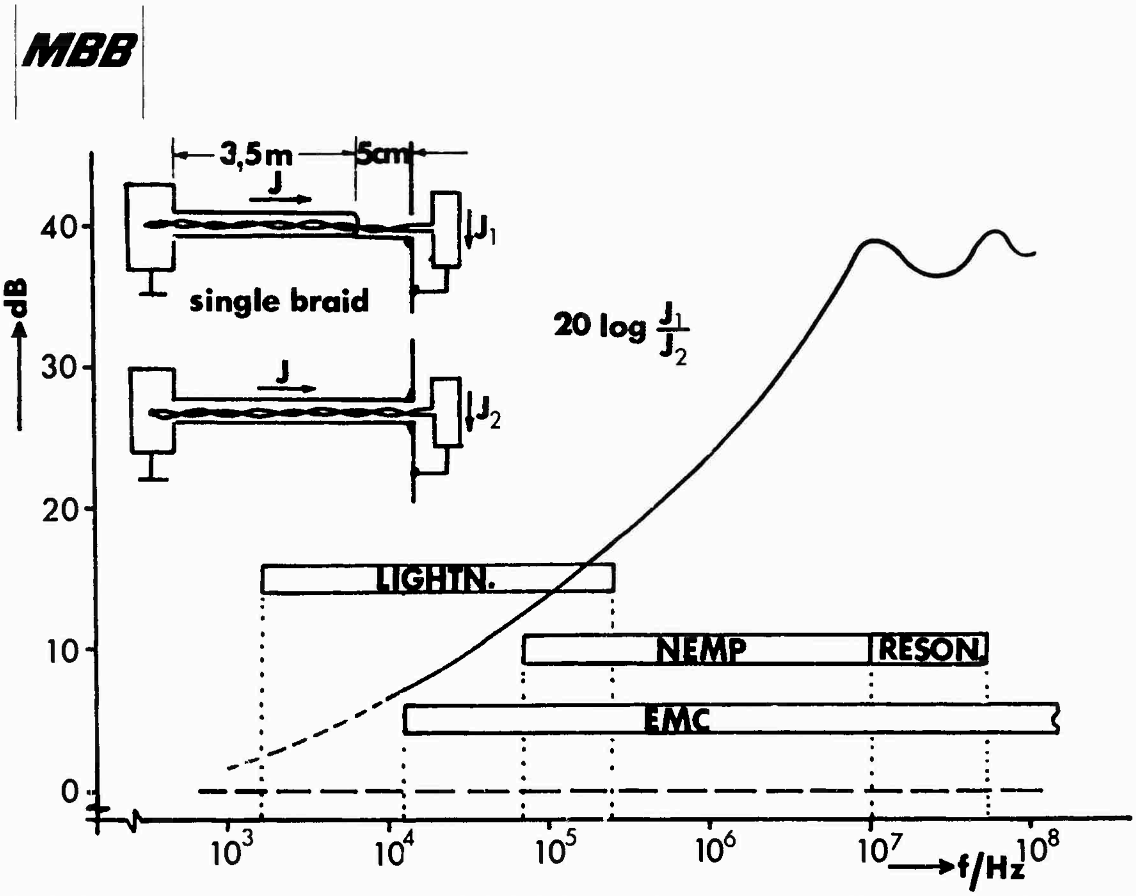

FIG 16: ADDITIONAL COUPLING OF A PIG-TAIL GROUNDED SHIELD

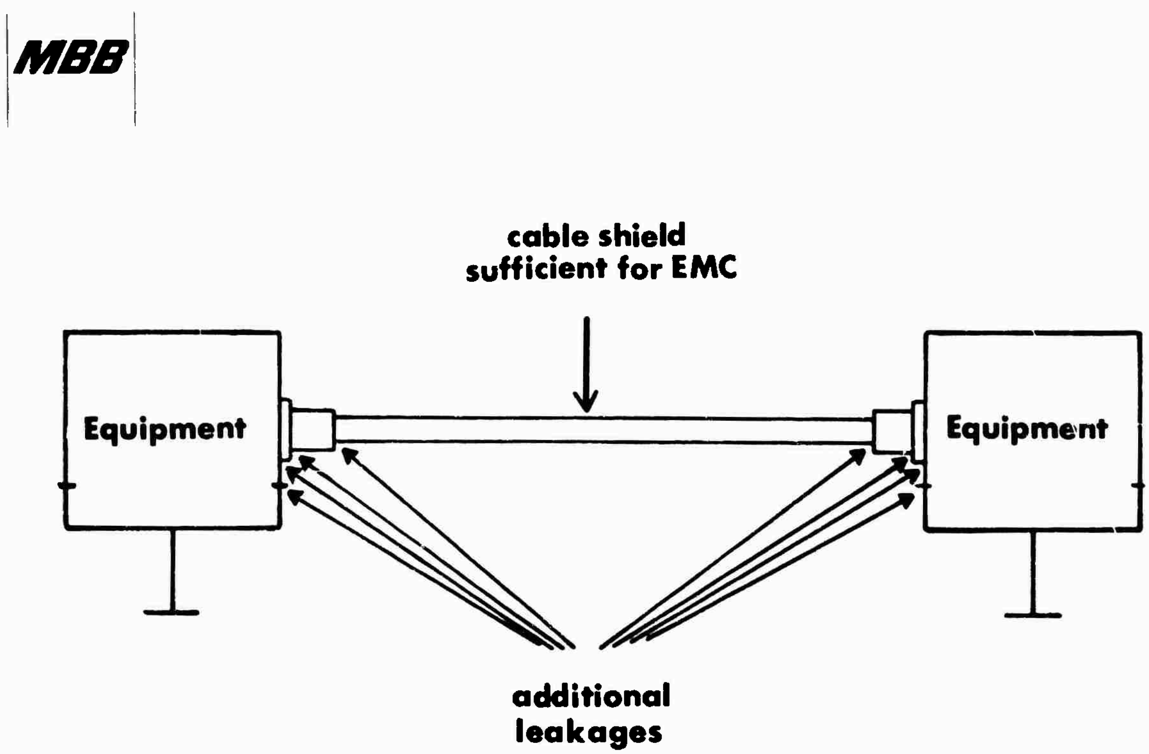

FIG 17: CONSIDERATION OF ADDITIONAL LEAKAGES

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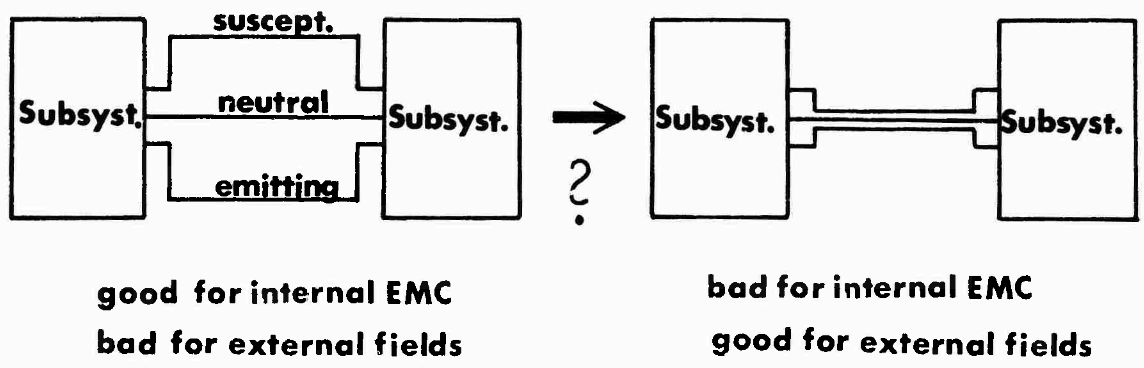

FIG 18: OTHER PHILOSOPHY OF CABLE ROUTING ?

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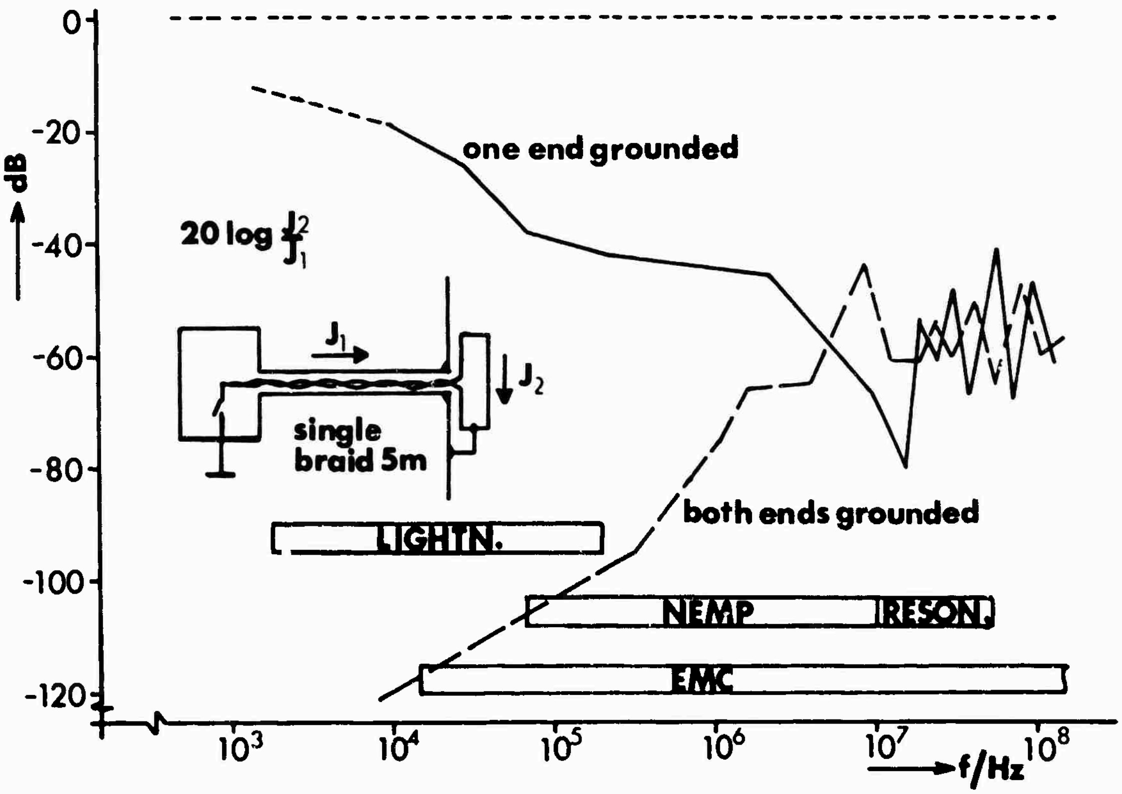

FIG 19: SIGNIFICANCE OF SIGNAL GROUNDING CONCEPT

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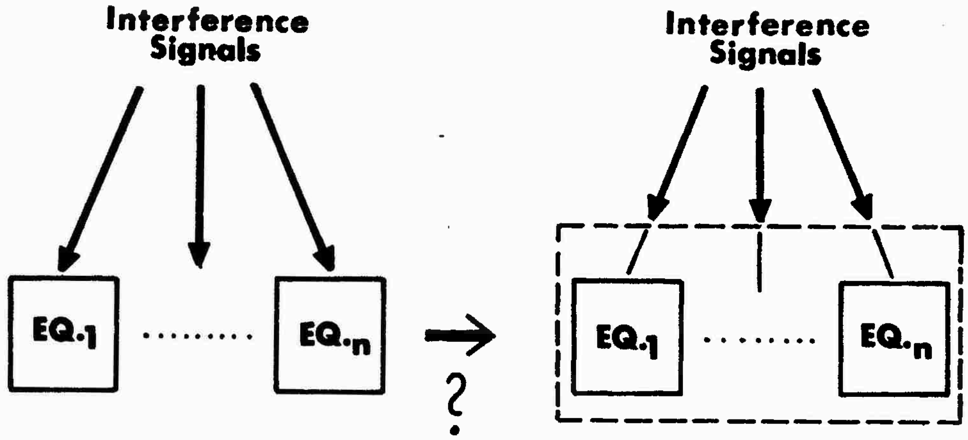

FIG 20: CONCENTRATION OF EQUIPMENT IN SHIELDED COMPARTMENTS ?

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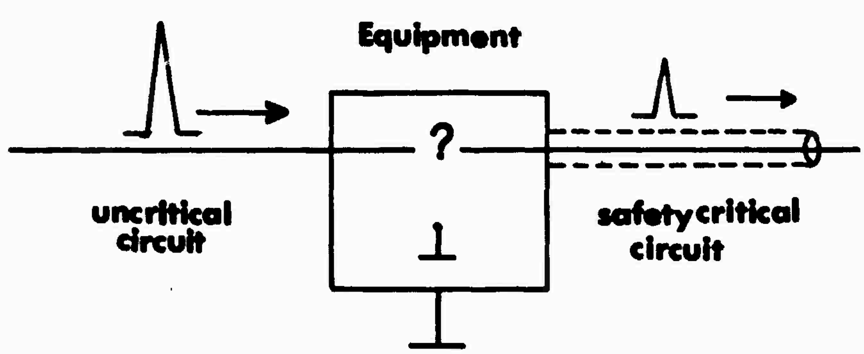

FIG 21: COUPLING BETWEEN DIFFERENT CLASSES OF SIGNALS VIA EQUIPMENT ?

DISCUSSION

W.R.Johnson, US

(1) Did you determine the difference in shielding effectiveness between aluminum and CFC by mathematical calculations or by tests?

(2) What test method(s) did you use?

Author's Reply

(1) Both curves, that means for aluminum and carbon fiber, have been calculated, but the results for carbon fiber have been controlled by measurements.

(2) The method of MIL-STD-285 has been used to measure the attenuation of the carbon fiber material.

AD P002845

AVIONICS/CREW STATION INTEGRATION

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United States of America

SUMMARY

The U.S. Navy has been encouraging advanced development concepts aimed at increasing the aircraft instrumentation performance for multi-platform applications of 1990's weapons systems. The three areas covered by the Navy's research and development effort are System Integration, Technology, and Human Factors. The objectives of these three areas are as follows:

- The System Integration objectives are to produce a system architecture easily adaptable to many platforms.

- Technology objectives are to determine the state of the art for displays, electronics, and controls.

- The Human Factors objectives are to determine the proper human-machine interfaces so that the ultimate crew station will be capable of providing the pilot with the proper display and controls performance to satisfy the diverse requirements of fighter, attack, ASW, fixed-wing, rotary-wing, and V/STOL platforms in both a one-man crew or two-man crew matrix.

All data/control interfaces among units of this crew station system and other platform subsystems will be via digital data buses and video multiplex buses. No individual discrete signal, data, or control lines will be needed. This paper discusses the six interfaces necessary to ensure the optimum development of this crew station, the predicted platform mission improvements, and the requisite life-cycle cost considerations. This concept will serve as a basis for planning the integration of the necessary hardware and software features in current and future weapons systems.

BACKGROUND

The requirement for a significantly improved approach to aircraft cockpit instrumentation and controls arises from the basic need for improved military effectiveness against all existing and planned piloted weapon systems. Increased effectiveness is needed to counter the threat posed by potentially hostile forces while accomplishing this goal within the bounds set by present constraints on essential resources.

U.S. Naval Air Forces will continue to be faced with a constantly escalating threat to their ability to maintain air superiority and sea control on a global basis, 24 hours a day and under instrument meteorological conditions - instrument flight rules (IMC-IFR).

As weapon system performance parities among competing force structures are achieved, as the life-cycle cost of operational equipment continues to increase, and as the sophistication of both the equipment and its required Naval air mission continues to grow, the greater becomes the importance of the human-machine interface in exploiting the maximum capabilities of the piloted aircraft.

Now, a need exists for a totally new approach to cockpit instrumentation and controls. In response to this need, the Naval Air Systems Command initiated development efforts on the Advanced Integrated Display System (AIDS) as the most feasible approach to meeting the demands of the 1990's weapons systems.

The AIDS will provide weapons systems improvements in the following three general areas of effectiveness, adaptability and supportability.

Effectiveness

- The tactical posture of the pilot will be improved in two ways: (1) there will be more time to assess a situation and make a decision through reduced visual scan time as compared to discrete instrumentation, and (2) there will be improved contact with the world "outside the cockpit" under all-weather conditions with tactical problems overlaid on automated situation displays.

- Aircraft availability will be improved through functional redundancy in display systems and through ranking of failure modes to distinguish between critical and non-critical situations.

Adaptability

- The modular nature of AIDS provides a building block capability that allows application of the complete system or its components in new or existing aircraft.

- While the most pressing need is seen as the single-place combat platform, both the technology and components are suited to the multi-manned aircraft as well.

- AIDS will employ technology that is similar to or compatible with sensor system developments likely to be in use over an extended period of time.

Supportability

- AIDS will reduce the number of individual types of these equipments in the Naval inventory.
- AIDS will reduce the number of individual skills now required to maintain aircraft instrument/display systems.
- AIDS will reduce training time requirements in each area for both pilots and maintenance personnel.
- AIDS will reduce downtime through maximum use of solid-state components and integrated circuitry that is compatible with built-in test (BIT) and automatic test equipment (ATE).

WEAPON SYSTEM COSTS

A major factor in the acquisition of any modern military system, particularly a weapons system, is the planning, control, and minimization of system life-cycle costs. These costs accrue from initial development and acquisition of a weapons system, and continue through the operational and support phases of the system. Costs of system operations must include training of operational and maintenance personnel, operational software development, and the development of adequate operational, intermediate, and depot level maintenance documentation. The elements of Integrated Logistics Support (ILS) come into play to ensure optimum support of the operational weapons systems throughout their life cycle.

With these points in mind, let us look at the various elements to be considered in the life-cycle cost planning of a crew station.

SYSTEMS DEVELOPMENT COSTS

The systems of the future must be capable of being assembled, much like the "Tinker Toys" we played with as a child. The hardware, software and interfaces must be so designed that they can be assembled, integrated and tested by medium-skilled personnel in a reasonably short (therefore less costly) period of time. The hardware and software must be so simple and so transparent to the technology that the interfacing of these hardware and software modules present only a minimal task.

Hardware Development

Programs such as the U.S. Air Force Digital Avionics Information Systems (DAIS) and the U.S. Navy Advanced Integrated Display System (AIDS) have developed hardware that can be used as prototypes for interchangeable modules in future aircraft and retrofit of existing weapons systems. The components of these systems are shown in Figure 1. Both programs are proving that modular concepts in hardware development are possible. Again, the technical problems are surmountable while the financial roadblocks are proving not to be. These modules, like any new model, have higher initial costs. The life-cycle costs, where the real savings will be, are not being taken into account because of today's fiscal limitations.

Software Development

Today, for a data processing system, 80 per cent of the total cost is for software. This software percentage is expected to increase by 1985 so that 90 per cent of the systems costs will be for the software.

Military Higher-Order Languages (HOL's) such as ADA (DoD), JOVIAL (USAF), and CMS-2 (USN), have been developed for the large quantity, high-speed computations associated with sensor signal processing. However, not enough attention is being paid to real-time interactive graphics requirements needed for today's system, much less the larger demands predicted for the future for large-scale computer graphics in real time.

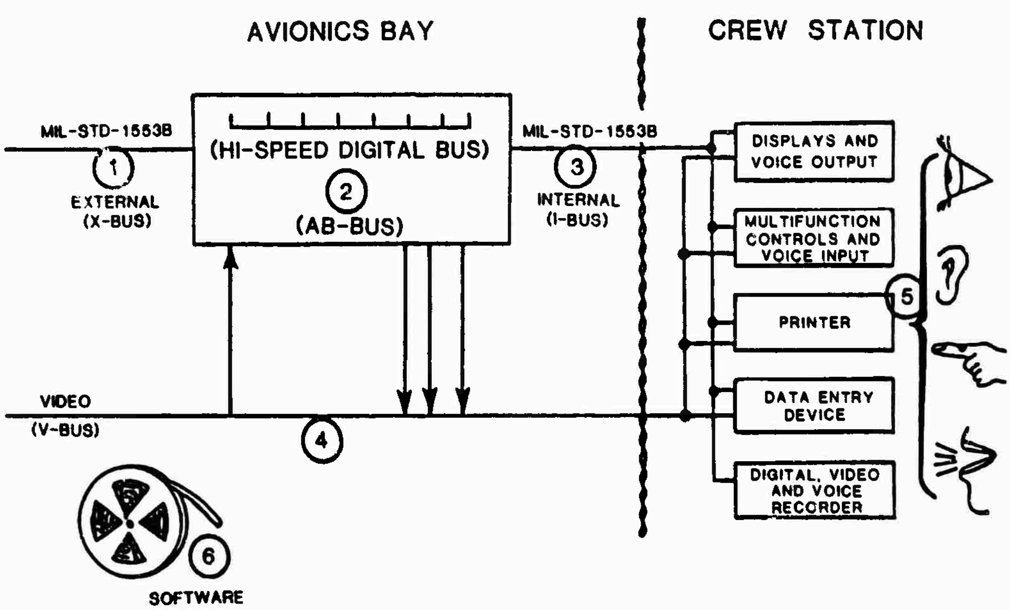

Figure 1. Displays and Control Interfaces

The languages must allow a non-programmer of the future to interact with these new systems so that medium-trained personnel can develop and evaluate new and innovative concepts in system operability. This should allow for more acceptability due to the adaptation, more quickly that realizable today, to the changing mission requirements and changing tactics.

Interface Development

The interface area is receiving more and more attention through the expanding use of MIL-STD-1553B. This expanding use is experiencing growing pains, as any new concepts do, but the development bugs are being ironed out. However, there are three problem areas that deserve increased attention.

First, the military with their 1553B, and the commercial airlines with the ARINC 429, are developing incompatible systems. Therefore, cost savings derived from large-quantity productions are going to be lost to the military since their share of the market is diminishing.

Second, there is the requirement for transmission of information at a higher rate than one megabit (1553B limit). This has been recognized and an analysis is being conducted of today's and future requirements for high-speed digital transmissions.

Third, there is the requirement, unique to the crew station community, for the transmission of video information. The AIDS has developed a video bus, very similar to a cable TV system, that will facilitate the initial development and future modification of integrated multi-function displays. The video bus utilizes standard composite TV for two important reasons; it is readily available and compatible equipment is very reasonable in cost. This is fine for 525-line monochrome systems. We are attempting to define what should be done for a color system and higher line rates such as 875 and 1024. The NTSC Color standard is not acceptable for small symbology. An R-G-B type of interface is some improvement, but requires too much bandwidth. This area requires much more effort than it is presently receiving.

PRODUCTION COSTS

The production of these systems must be kept in mind during the development phase. The electronics technology has made such tremendous strides with LSI and VLSI that other technologies have been left in the dust. Recent advancements in optics, such as fiber optics and diffraction optics, may make this expensive technology more reasonable in the future. But other areas, such as flat panels, must be producible on a large scale with automation maximized.

OPERATIONAL COSTS

Operational costs are directly relatable to operational complexity. Therefore, the primary goals in effective weapons systems operation should be to make the human-machine interface so easy to operate that operator training and proficiency update requirements would become almost negligible. This can be achieved by making the machine as adaptive as possible to stimulate the natural senses of the human. Long-term cost savings could be attained, not only in training and proficiency (in both simulator and flight time) costs, but though reducing loss of equipment due to "operator error."

If we think of the human-machine interface simply as communication between the operator and the machine, then perhaps an analogy can be drawn to communication between one person and another person.

The person-to-person intercommuncations uses visual (alphanumeric, graphic and pictorial), auditory (speech) and motion. Therefore, if we are to make the person-to-machine communications as effective as person-to-person communications, we must have:

1. Printed information
2. Graphical information
3. Pictorial information
4. Two-way verbal communications
5. Motion and position sensing.

Assuming again that the closer we approach person-to-person communication, the better, then, the graphical and pictorial information must be, in both 2D and 3D and with all information in full color. The system must be reactive to the individual operator and must be tailored to his specific needs, both normal and abnormal. The Mark I individuals, with whom we must operate, are all different. To expect all individuals to fit one mold is nice in theory, but impossible in reality.

The systems of the future will have the capability for programmed "level-of-acceptable performance" defined for every important task of every mission mode. The system can evaluate the operator's performance and, if it falls below this level, it will take over more and more of the functions until the operator's performance is back to an acceptable level. As the performance exceeds this level by a specified amount, the system offers to give back to the operator some of the functions, if he wants them. This level of performance may be raised, from some specified lower limit, by the operator as he undergoes his training. This would allow the operator to decide how many functions and in what priority he wishes to transfer the the system. Of course, this delta can be modified up or down (to the lower limit) throughout the operator's experience. The term "operator" is used here because performance is applicable not only to the pilot, but could be implemented for navigators, sensor station operators, tactical officers, etc.

Also during training, the operator can have some freedom in selecting the type of information that is presented to him during the various mission modes, as well as the response of the system to his commands. This will allow the "picture person" and the "word person" to tailor the system to his individualized tastes, thereby improving acceptability, improving operability, and reducing life-cycle costs.

This natural system can almost certainly include voice communication, meaning voice recognition (phrases first, then continuous speech) and voice synthesis (completely synthetic or reconstructed digitally stored voice). The Helmet Mounted Display (HMD) will be capable of taking over an increasingly larger and larger amount of the information presentation until it is the only display in the crew station. The instrument panel will be black and a synthetic instrument panel will be generated on the HMD when the operator looks in that direction. Eventually, that requirement will be deleted and the operator will keep his head and eyes out of the crew station at all times. The HMD evolution will be monocular, biocular and then binocular, starting in monochrome and eventually evolving to color because, as stated earlier, seeing images in color and 3D are the natural way of viewing the real world.

Multifunction controls are becoming increasingly accepted. They have the capability of being introduced into the consoles initially and finally right into the armrests of the seat. Feedback systems to the HMD will tell the operator which switch his finger is on before he presses the button so that he will not have to bring his eyes back into the crew station to view the multifunction controls. The multifunction controls and voice recognition will probably become so intertwined that each will be a primary mode of input for some individuals while the other will be back-up.

All of these increases in capability will be reflected in reduced operational costs, due mainly to training time reductions and decreased loss of equipment due to "operator error".

SUPPORT COSTS

System life-cycle costs can be further reduced and controlled through effective planning of the Integrated Logistics Support (ILS) and system reliability and maintainability (R&M).

The necessary steps to solving maintenance problems include the following:

1. Recognizing a malfunction
2. Isolating the malfunction
3. Correcting the malfunction
4. Verifying the correction
5. Documenting the maintenance action

The AIDS Program includes the following equipment at the crew station:

AIDS Equipment	Common Name
Displays	CRT
Multifunction Controls	Keyboard
Briefing Information Entry Device	Tape Drive
Maintenance Recorder	Printer

If one looks at the list on the right, it is not hard to call the crew station a computer terminal station. Thus, the crew station can now become the maintenance shop for all the hardware in that particular aircraft. Available are most of the necessary tools (BIT, diagnostics, instructions, etc.) to be used by the maintenance person to perform on-line tests to effect all of the remedial maintenance required, thereby reducing system down time and, consequently, costs.

Imagine the following scenario:

Our maintenance section is requested to ensure that 10 to 15 F-25's, that have just landed, will be ready for this afternoon's mission.

Joe Average and his counterparts are assigned to report upon the status of each aircraft. Joe goes to BUNO 17369 and, without need of electrical power, reads the printout from the crew station printer to his supervisor over a portable communication link. (The printer had developed two copies of the report upon landing, listing all malfunctions, when they occurred, if they are intermittent, and what was the last status of the malfunctioning equipment. The pilot tore off one copy to be submitted during his debriefing, leaving the other copy in the crew station for the maintenance personnel.) The maintenance supervisor informs Joe that this aircraft is needed and that Joe should be able to correct these malfunctions in time for this afternoon's flight.

Beside each malfunction on the printout is a number that coincides with the number of the digital cassette containing the diagnostic software for that problem. Joe selects the cassette from the container he carries with him. Inserting the cassette into the Tape Drive will run a diagnostic program and, on the CRT, display the corrective action required. Questions can be asked by Joe if he is not sure of what steps he must take. In reply, he might receive the following instructions:

1. Go to Avionics Bay 1 (front-left)

2. Third shelf from top

3. Replace 14th module from the right (MODULE 743)

4. Tools needed

- Cross-point screwdriver
- Cutting pliers
- Needle-nose pliers

After Joe is convinced that he understands the operations, he requests a chit for Module 743. The printer then prints the chit for him as well as the list of tools required.

After Joe has submitted the chit and received Module 743 and the tools from supply, he goes to Avionics Bay 1 in the aircraft and plugs his helmet connection into shelf number three. Information is presented on the visor of his helmet and over his earphones that he is indeed in Avionics Bay 1 and is at the third shelf from the top. (Or, if he is at the wrong location, he will be informed that he has made a mistake and is in, for example, Bay 5, the second shelf.) The removal of the 14th module from the right is also verified (or not, if he is wrong). The replacement of this module initiates the rerunning of the diagnostic program and tells him that he has indeed corrected the malfunction. He requests a printout of the maintenance action and receives a printout of the corrective actions taken, as well as the time taken to correct the malfunction. This printout will be turned in to his maintenance supervisor for inclusion in the next maintenance report.

Joe had to do minimal reading. He had a chance to assure himself of the steps he was going to take, before he started, by requesting information from an impersonal machine. He was reassured along the way that he was correct, step by step. He was congratulated in the end for a job well done and, most importantly, he personally did not have to fill out one form, yet all the required forms were filled out correctly. This improved maintenance action will result in improved logistics.

Had this been a LAMPS helicopter or a VSTOL aircraft operating from a destroyer, the cockpit may have been the only space available for any maintenance investigation aboard the ship.

INTERFACES

Figure 1 portrays the six interfaces that must be controlled for effective crew station design.

These interfaces are as follows:

1. External Bus (X-Bus)

The X-Bus proposed for transmission of digital data from aircraft sensors and computers to the avionics bay display electronics would be a serial digital bus that would conform to MIL-STD-1553B. A pair of buses would be required to provide redundancy.

2. Avionics Bay Bus (AB-Bus)

The AB-Bus proposed for transfer of digital data between various user elements installed in the aircraft avionics bay such as Digital Processor, Mass Memory, Raster Symbol Generator, X-Bus Interface and I-Bus Interface would require a high-speed, 16-bit, parallel, digital bus.

The basic purpose of the AB-Bus is to transfer data from one user element to another in a distributed processor system. The AB-Bus has a number of input and output interrupts corresponding to the number of elements connected to the bus. Each element on the bus, when selected, has a 512-k word address capability and communicates with the bus controller over a pair of input and output interrupts. The input interrupts are used for user element communications to the AB-Bus Controller and output interrupts are used for AB-Bus controller to the user element.

3. Internal Bus (I-Bus)

The I-Bus proposed for transmission of digital data from the aircraft avionics bay to the crew station displays and controls would also be a serial digital bus that would conform to the MIL-STD-1553B. As for the X-Bus, the I-Bus will consist of a pair of buses. However, both I-buses could be in use full time. Then the unlikely failure of one bus would require the reconfiguration of the remaining bus to operate on a degraded mode. The system would be designed so that the bus controller would monitor the bus and, when it detects a failure, would automatically institute a bus reconfiguration according to a set of predefined priorities.

4. Video Bus (V-Bus)

The V-Bus, through the use of a video multiplexing system, will distribute several video and sync signals among multiple display terminals. This type of video signal distribution is similar to that used in commercial cable television. The V-Bus permits signals from multiple sources to be carried on one bus for display at selected moments on any number of crew station displays. The ability to transmit multiple video signals enables the sources of the signal as well as display units to be changed or new ones to be added without requiring major rewiring of the aircraft. The primary requirement of the signal sources and displays is that they are compatible to the characteristics to be defined for both the video bus and data bus.

Each display unit contains a Digitally Tuned Receiver (DTR) that is connected to a data bus. Commands can be sent through the DTR over the data bus to tune a display to receive video from any of the external sources, generally sensors, TV missiles, or the Raster Symbol Generator (RSG) located in the avionics bay of the aircraft. The RSG, through a DTR, can be commanded to receive the sensor data and combine it with symbology and retransmit the combined video signal to a crew station display unit.

To ensure fail-safe conditions, two video buses and two data buses would be installed with the bus controller monitoring bus operation. Should the controller detect failure of one bus, the second bus would be reconfigured to operate in a degraded mode to permit transmission of required signals. A priority system would have to be developed as a function of critical parameters to be defined to enable successful completion of the aircraft mission.

5. Operator/Machine Interface

The operator/machine interface is receiving more and more attention. The use of multifunction displays and controls hopefully will preclude the following results of a study of five years of Naval aircraft accidents:

- Incorrect use of emergency procedures: 33 aircraft destroyed, 13 aircraft damaged, 19 fatalities.
- Incorrect use of checklist: 5 aircraft destroyed, 18 aircraft damaged.
- Lack of stabilator position indicator (peculiar to F-4): 8 aircraft destroyed, 6 fatalities.
- Lack of subsystem malfunction advisory information: 42 aircraft destroyed, 65 aircraft damaged, 75 fatalities.
- Lack of midair warning system: 8 aircraft destroyed, 7 aircraft damaged, 10 fatalities.
- Lack of VN envelope information to pilot: 42 aircraft destroyed, 8 aircraft damaged, 27 fatalities.
- Lack of VQ envelope information to pilot: 18 aircraft destroyed, 5 aircraft damaged, 20 fatalities.
- Lack of altitude warning system: 34 aircraft destroyed, 6 aircraft damaged, 59 fatalities.
- Inadequate precision approach information: 15 aircraft destroyed, 46 aircraft damaged, 4 fatalities.
- Inadequate CVA precision departure information (reverse ACLS): 16 aircraft destroyed, 21 fatalities.
- Lack of accurate rate-of-sink indications: 6 aircraft destroyed, 2 aircraft damaged, 7 fatalities.

What is required is the capability to demonstrate a coherent solution to the problem of proliferation and nonstandardization of aircraft displays and controls. To achieve this purpose, efforts are being directed toward development of crew stations based upon digital computers, utilizing a high-order programming language. The flexibility of such digital computers and their accompanying digitally driven displays has created radically new capabilities to be utilized in the design of crew stations. The total dependence on the use of dedicated, round-dial and taped instruments is at an end. The digital computer allows the implementation of multiprogrammable electro-optica displays, such as those used in the F-18; it also allows for the use of programmable controls such as those used in the F-16 stores management panel. The electro-optical, multifunction displays and controls offer significant advantages over their dedicated counterparts in that one electro-optical display, through the use of various display format changes, can encompass the information presented on many dedicated displays. Early emphasis in both Air Force and the Navy has been on transferring formats from electromechanical instruments to cathode ray tubes (CRT's). The product of these early efforts has come to fruition and is extensively employed in the F-18 aircraft and, to a more limited extent, in the F-16 aircraft. There is reasonable concern that the pilot may have trouble in fully utilizing the tremendous amount of alphanumeric information currently being presented to him on the electro-optical devices. We may have reached a state where the information processing of the human is a limiting factor in the use of more alphanumeric information. The answer to this concern and the objective of this effort is the simulation and evaluation of new formats that are based upon vectorgraphic or pictorial information as opposed to the alphanumeric information that has been used in the past.

6. Software Interface

The software interface, if standardized, will provide a graphics programming system that offers the advantages of high-level support and facilities to meet the unique technical requirements for multifunction displays and controls. In addition, other advantages are:

- Reduced cost of programming.
- Increased assurance of software reliability.
- Reduced cost through ease of modification.
- Portability and reusability through processor and display device independence.
- Improved software through utilization of state-of-the-art, real-time graphics techniques.

The software functional requirements have been divided into the following three groups:

- Hardware evaluation

- Operational requirements
- Support requirements

Operational Software

The AIDS operational software provides the environment in which the application software are run. This environment may be considered a virtual machine with a well-defined software interface, applicable to a wide variety of processor and system architectures. Even when the underlying physical machine changes, the software interface to the virtual machine will still remain the same.

The services provided may be divided into four general categories: executive functions; input/output functions; file system functions; and reconfiguration control. Executive functions include processor and primary memory allocation and intertask communication and coordination. The input/output functions govern all transactions between the AIDS data processor and any external device. File system functions provide access to data organized as units of related information. The reconfiguration control functions maintain alternative sources for critical data and help the applications functions to determine which peripherals are usable.

Support Software

This software is composed of various tools associated with the Naval Air Development Center's Central Computer Complex and includes items needed to develop the operational software. The two most important tools are the AIDS Display Formatter (ADF) and the AIDS Command Formatter (ACF).

The ADF is a system for preparing the AIDS display-driving software. The actual mechanics of translating display formats into display programs are handled by a graphics, real-time display language. In order that these display programs can communicate with the display update programs that are part of the Operational Display Software (ODS), some conventions on naming of the rapid changes will be promulgated. The display update programs will pass the appropriate name to the graphics, real-time display language run-time routines that will search for the name in the record of image structure in order to locate the appropriate modification code to be passed to the Symbol Generator(s). A pictorial representation of the ADF is shown in Figure 2.

The ACF is a translator that accepts statements in the AIDS Command Language (ACOL) and produces data declarations in CMS-2 for inclusion in the data processor source modules as well as data declarations in the microprocessor assembly language for inclusion in the source modules located in the Integrated Control Set (ICS) itself. The ACOL statements completely define the facilities provided to the pilot on the ICS.

The microprocessor assembly language data definitions specify a hierarchical structure of ICS states, along with button labels and button depression responses appropriate to those states. The responses may be internal to ICS (for example, changing an ICS state in response to a button depression) or may involve ICS sending a command to the data processor. The CMS-2 data definitions describe these commands; the definitions cover command code, data sources and command destination. A pictorial representation of the ACF is shown in Figure 3.

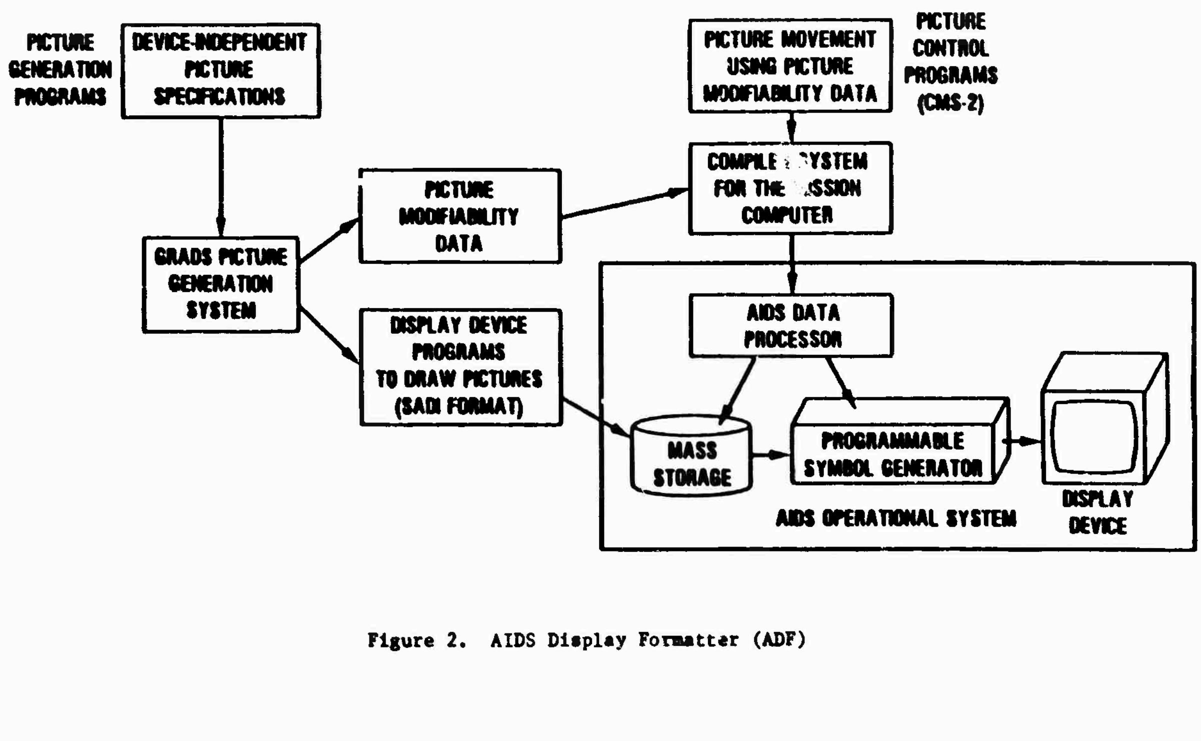

Figure 2. AIDS Display Formatter (ADF)

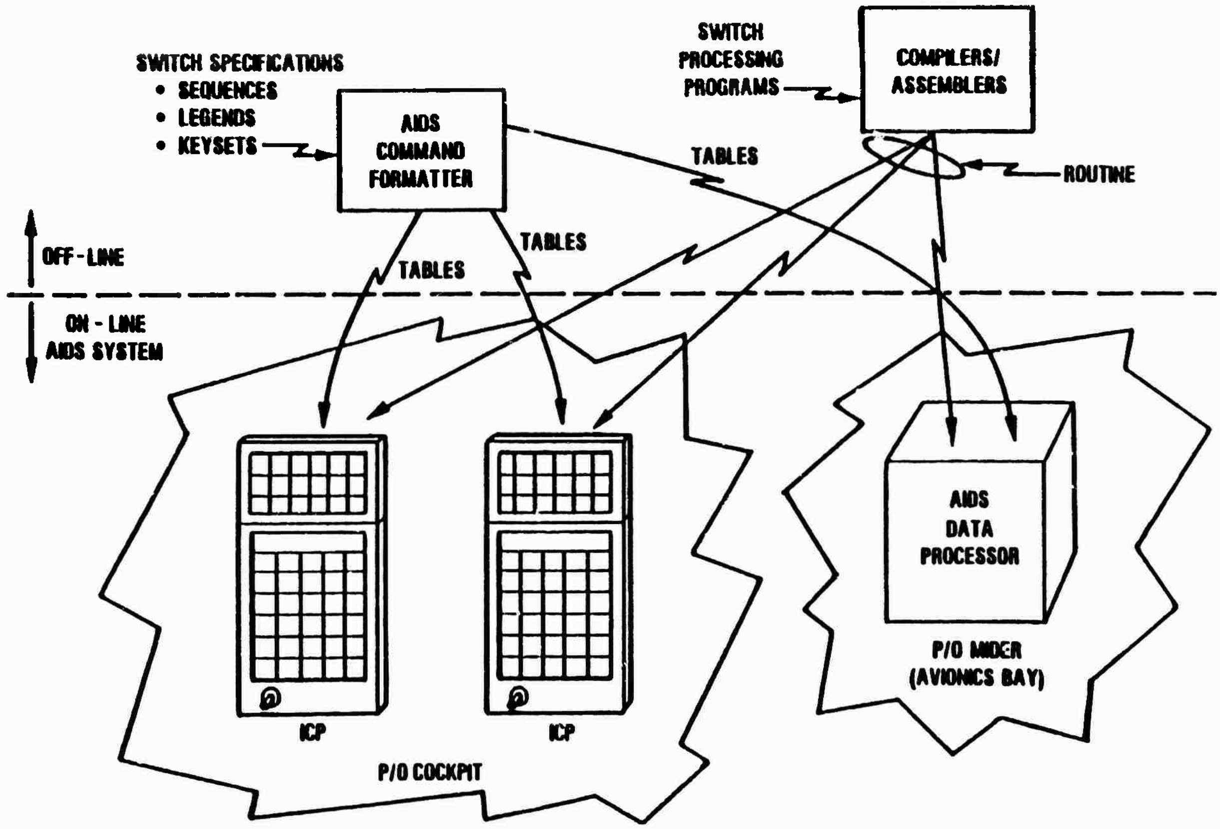

Figure 3. AIDS Command Formatter (ACF)

CONCLUSIONS

Military airborne platforms of the 1990's will require an expanded and reliable human-machine interface with crew station instrumentation in order to optimize the tactical position of the pilot. State-of-the-art advancements in display hardware and in software and interface designs are critically needed to achieve weapon system crew station instrumentation that is adaptable to many platforms. The display and control interfaces, as shown in Figure 1, portray the four crew station hardware interfaces, the human-machine interface, and the software interface that would meet these needs.

However, as new and improved hardware and software become available, the life-cycle costs must be reduced in order to achieve the necessary operational effectiveness of the future weapon systems. Rigid controls in the design and integration of the six interfaces is crucial to the reduction of life-cycle costs previously described. Reduction of these costs will be the only way that these systems will be introduced. An improvement in the effectiveness, adaptability, and supportability of crew station instrumentation, described in the Background will, of course, be possible only if these innovative concepts are indeed introduced into the fleet. To attain the desired mission requirements, the specification, production and control of these six interfaces must be established to achieve crew station compatibility for multiplatform applications.

DISCUSSION

W.R.Johnson, US

It has been my experience that it is extremely difficult to sell Life Cycle Cost Savings if it results in significant increase in initial procurement cost. Do you have an idea as to how to handle this problem?

Author's Reply

I have had the same experience. It is forums like this that should be utilized to convince high level decision makers that life cycle cost consideration is the only long term solution. Short cuts today and bandaids later to fix the mistakes are self-defeating.

A.O.Ward, UK

Is the display software produced by your offline system fully interactive or is it just animated to show track movement of symbology?

Author's Reply

Both the display and the multifunction control software are completely interactive.

LE COMBINE DE VISUALISATION

PAR

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RESUME

L'appellation "combiné de visualisation" correspond à un ensamble mécanique unique regroupant un viseur tête hauta et un écran tête basse. Las imageries tête haute sont présentéas colllimatées, les imagaries tête basse peuvent être collimatéas ou focalisées dans un plan fixe.

Un tel systèma permat d'envisager la possibilité de divers typas d'utilisation :

- extension du champ viseur vars le bas, lorsque la visualisation tête basse est collimatée.
- un allègement de la symbologie tête haute par une meilleure répartition sur tout le combiné, lorsque la visualisation têta basse est collimatée.
- lorsque la visualisation tête basse est focalisée à una distanca fixe, elle peut être associée à un autre écran tête basse en planche de bord.

INTRODUCTION

Les problèmes de trensition au passage visualisation tête haute - visualisation tête basse (accomodation de l'oeil, discontinuité de l'informetion), nous ont amené à proposer un concept de combiné de visualisation ; il s'agit d'un ensemble mécanique unique regroupant un viseur tête haute et un écran tête basse, utilisant de nouvelles technologies : optiques à diffraction, collimation des imegeries tête basse.

Ce concept doit permattre d'améliorer l'efficecité des échanges pilote - système d'armes, en utilisant la partie tête basse soit collimatée, soit focelisée à une distance fixe. Différents types d'utilisation seront envisagés dans ce papier, ces propositions restant dépendentes de le faisabilité technique.

1-ORGANISATIONS DES PLANCHES DE BORD ACTUELLES

1.1 - Répartition des systèmes de visualisetion

Il existe actuellement deux catégories de systèmes de visualisation :

- des systèmes dits "tête haute" : l'imagerie est alors visualisée collimatée, à travers un viseur, situé au-dessus de la planche de bord, et permettant le pilotage de l'avion, (pilotage de base et action à court terme en fonction de la phase de la mission en cours) par l'obervation simultanée du paysage extérieur et des informations vues en superposition.
- des systèmes dits "tête basse" : l'imagerie est alors visualisée non collimatée sur un ou plusieurs écrans, situés sur la planche de bord, permettant la présentation des images délivrées par les différents capteurs embarqués ou autres dispositifs délivrant une vidéo et servant d'interface SNA par l'intermédiaire de commandes périphériques.

1.2 - Etudes des différents problèmes

1.2.1 - Transition optique tête haute -tête basse

Le passage des visualisations présentées focalisées à l'infini en tête haute, aux visualisations non collimatées en tête basse, présentées dans le plan de la planche de bord, pose un problème d'accomodation de l'oeil, de même que la différence de luminosité moyenne.

De plus un écran tête basse ne se trouve jamais directement sous le collimateur tête haute. L'oeil a donc un certain circuit à parcourir, circuit qui peut être encore plus grand s'il doit aller "chercher" des écrans tête basse latéraux.

1.2.2 - Transition du type d'imagerie tête haute - tête basse

Chacun des deux systèmes de visualisation présente des imageries souvent spécifiques sans continuité dans l'information présentée ceci bien évidemment en partant du principe que des images collimatées en tête haute et toujours non collimatées en tête basse ne peuvent avoir que des utilisations bien différentes.

En effet suivant les phases du vol, le pilote souhaite travailler en gardant la vue sur l'extérieur (c'est le cas chaque fois que ses centres d'intérêts peuvent être observés au dehors) ; il utilise alors le viseur. Par contre lorsque ses centres d'intérêt sont hors de vue, il ne peut que se reporter en tête basse pour y chercher une information délivrée par l'intermédiaire de capteurs.

1.2.3 - Charge d'informations présentées sur le viseur

Les imageries tête haute sont souvent chargées d'informations statiques non superposables au paysage et qui gênent la vision du monde extérieur.

2 - DEFINITION DU COMBINE DE VISUALISATION

Pour tenter d'apporter des solutions aux problèmes évoqués au chapitre précédent, il faut un système de visualisation plus homogène physiquement et optiquement, moins dissociable c'est-à-dire s'adaptant indifféremment à plusieurs types d'imageries.

Ce système sera présenté sous le nom de : combiné de visualisation.

Les différents types d'utilisation du combiné de visualisation, qui seront évoqués dans ce papier, doivent être considérés comme des objectifs répondant aux problèmes posés, mais restant dépendant de la faisabilité technique.

2.1 - Le combiné de visualisation

Le combiné de visualisation est un ensemble mécanique unique regroupant un viseur tête haute et un écran tête basse. Ce concept de combiné permet de minimiser l'épaisseur du linteau horizontal séparant le collimateur tête haute (CTH) et la visualisation tête basse (VTB).

Le collimateur tête haute peut être soit un viseur à optique classique, soit un viseur utilisant les nouvelles technologies d'optique à diffraction (glace holographique)*. La visualisation tête basse présente des imageries qui peuvent être soit collimatées, soit focalisées dans un plan particulier.

2.2 - Types d'utilisation

Le combiné de visualisation pourra être utilisé de deux façons :

- VTB collimatée : les imageries tête basse étant focalisées à l'infini, on annule ainsi les problèmes d'adaptation visuelle au passage tête haute - tête basse. Cet ensemble est alors utilisé pour présenter :
  . une imagerie unique partant du champ viseur et s'étendant vers le bas au champ tête basse, superposable au paysage extérieur (paysage effectivement perçu à travers le viseur pour une partie et qui serait vu à travers la planche de bord et le nez de l'avion s'ils étaient transparents pour l'autre partie)

* Nous n'envisageons par la suite que cette 2ème solution.

. una imageria différente en tête basse de calle du viseur qui permettra par exemple lorsque le chamr viseur est suffisant, une meilleure répartition des informations tout en permettant une transition aisée tête naute -tête basse.

- VTB focalisée à una distanca fixa : les imageries tête basse ne sont plus collimatées. Cette configuration est plus adaptée à l'association "visuelle" avec le ou les autres écrans tête basse et correspond plus à l'utilisation actuella.

2.3 - Solutions apportées

Le combiné ainsi réalisé permet :

- une amélioration de la transition tête haute - têta basse et possibilité d'extension du champ viseur en utilisant la tête basse collimatée
- une utilisation de la têta basse plus adaptée à chaque phase de mission, c'est-à-dire non spécifique d'un type de visualisation
- une plus granda homogénéîté des informations présentées qui ne sont plus spécifiques de l'écran tête basse sur lequel alles apparaissent, mais de l'utilisation choisia du combiné.

3 - AMENAGEMENT EN CABINE

Nous considèrerons l'aménagement du combiné de visualisation dans l'avion, en se basant sur l'organisation futur du poste d'équipage telle que nous l'envisageons.

3.1 - Dascription de l'anvironnement cabine

L'aménagement de la cabine repose sur la conception du siège pilote qui permet une meilleure tolérance aux facteurs de charge élevés. Pour ce faire, le dossier du siège est incliné d'un angle de 50° avec l'axe z.

La première conséquence importante est que le manche et la manette des gaz ne peuvent être que latéraux.

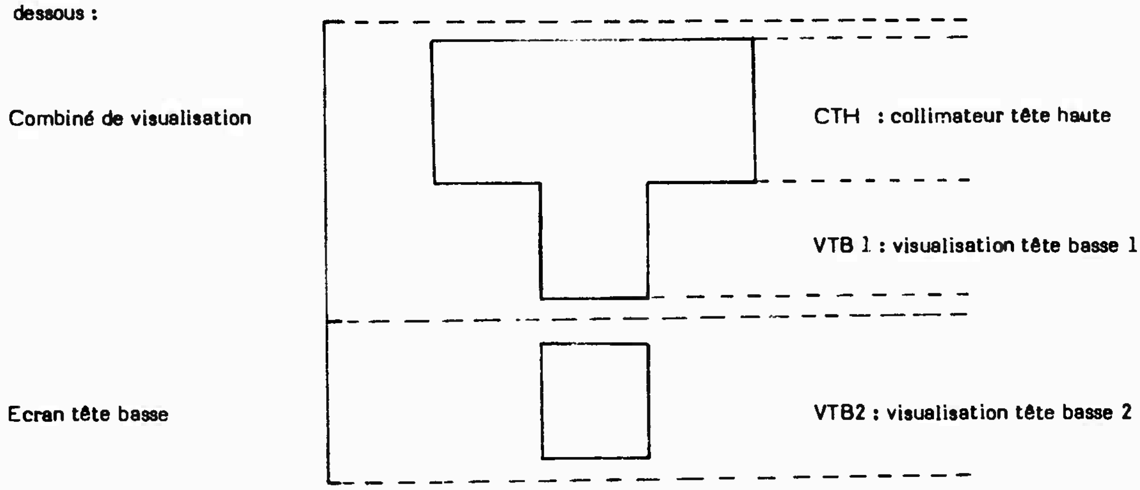
La seconde est que la planche de bord se trouve alors réduite à une bande verticale (comme le montre la planche 1) at à deux petits panneaux implantés au-dassus des pieds.

Cet aménagement permet l'installation des équipements de visualisation sur la bande verticale, d'instrumants de secours sur les planchettas da bouts de pieds, de claviers sur l'avant des banquettes

Planche n° 1

3.2 - Intégration du combiné de visualisation

Dans un tel contexte, le combiné de visualisation s'intègre facilement, comme indiqué sur le dessin ci-dessous :



La VTB2 faisant suite au combiné, est un écran tête basse, présentant des imageries dans le plan de la planche de bord, tel qu'il est actuellement utilisé.

Cette installation permet une visualisation dans un seul axe (haut-bas ou bas-haut) dont la transition entre chaque terminal est fonction du type d'utilisation du combiné.

4 - PERFORMANCES ET UTILISATION

4.1 - Performances

Le collimateur tête haute dit "holographique" est caractérisé par :

- la présentation d'un champ de 30° en latéral sur 20° en vertical
- la visualisation d'imageries trichrome.

La tête basse VTB1 est caractérisée par :

- deux plans de focalisation, soit l'infini, soit le même plan que VTB2, c'est-à-dire le plan de la planche de bord. Le passage d'un plan à l'autre pourra être soit automatique (automatisme déclenché par la phase de la mission en cours) soit manuel
- la visualisation d'imageries polychromes
- la face avant est un rectangle de grand côté horizontal, de dimensions angulaires (ramenées à la distance de la VTB2), équivalentes à 7" x 5".

Nota : La face avant de VTB2 est un carré de 7" de côté.
Les imageries présentées sont polychromes.

4.2 - Utilisations

4.2.1 - Utilisation VTB1 collimatée

4.2.1.1- En extension du champ viseur

Le principe d'utilisation est alors la visualisation au centre du CTH et dans le prolongement sur la VTB1, d'une imagerie superposable au paysage extérieur, pouvant provenir d'un générateur de terrain et/ou d'un boîtier générateur de symboles.

Sur cette imagerie viennent s'ajouter les réticules de pilotage et les réticules spécifiques de la phase de la mission en cours, qui constituent une liste unique pour le combiné, et peuvent, donc, dans la limite de leur domaine opérationnel, passer indifféremment du CTH à la VTB1 et réciproquement.

Ce "fond vidéo" et réticules associés constituent alors le centre d'intérêt du pilote.

Les fonctions commandas et consultation sont visualisées dans l'espace restant c'ast-à-dire sur las bandeaux latéraux.

Sur le CTH, on présente en bandeau tous las réticules fixes, c'ast-à-dire las compteurs, échelles, signalisations de mode de fontionnement.

Sur la VTB 1, on présanta en bandaau les labels correspondants à des sélections de mode de fonctionnemant, de typa da visualisation. compatibles avec la phase de la mission en cours.

Un réticula de désignation peut être déplacé indifféremment de la tête haute à la têta basse, à l'aide d'une commande à accès rapida, sarvant aussi bian à désigner un labal sur la VTB 1 ou un point de visée sur le CTH.

4.2.1.2 - En aide à transition tête haute - tête basse

Dans ce moda d'utilisation, on présente sur tout le champ tête haute les imageries superposables au paysage at en tête basse las informations nécessaires à la phase du vol en cours mais non directement liées au monda axtérieur, par example les compteurs, las échelles.

4.2.2 - Utilisation VTB 1 focalisée à una distance fixe

L'utilisation tête basse correspond plus aux habitudes actuelles.

La VTB1 est alors "désolidarisée" optiquement du CTH pour s'associer à la VTB2. Cette utilisation correspond plus aux phases de la mission, assistées d'imageries non projetables en tête haute ou aux phases de préparation du système da navigation et d'armemant (SNA).

L'association des imageries VTB1 - VTB2 peut être de plusieurs types :

- des imageries capteurs sont présentées sur les deux écrans ; elles sont opérationnellement complémentaires
- une imagerie capteur ast présentée sur l'un, una image cartographique sur l'autre.
  - une imagerie capteur est présentée sur l'un et la "page" de commandes ou de gastion correspondante sur l'autra.

Dans cartains cas de consultation du système avion, las imageries VTB1 sont dissociées de celle de VTB2, pour présanter au pilote, un tableau das pannes, d'états motaurs, d'états du systèmes radiocommunication.

Dans tous les cas les réticules associés sont spécifiques de l'écran sur lequel ils sont visualisés, des bandaaux latéraux sont résarvés pour des labals permettant l'accès aux commandes, par désignation.

5 -EXEMPLES D'UTILISATION

5.1 - Utilisation VTB 1 collimatée :

- Présentation du relief synthétique

Le relief synthétique est une représentation du terrain survolé, élaborée à partir d'una mémoire da masse contanant las données numériques nécassaires. Ce tarrain se superpose* en tête hauta au terrain réel survolé et se suparposerait en tête bassa au terrain réel s'il était vu (d'où le concept de planche de bord transparente).

Cette représentation permet donc d'effectuer das vols à très basse altitude qualles ques soient les conditions météorologiques, de jour ou de nuit. (voir planche 2).

La projection de cette imagerie sur le combiné permet par rapport aux solutions actuelles, la représentation du terrain selon un champ plus étendu en longitudinal et en latéral ; ce procédé, dans des conditions de mauvaise visibilité donne au pilote une meilleure perception tant au niveau perspective que richesse d'informations du relief dans lequel il évolue.

Dans certains cas d'approches particulières (relief, endommagements...), ce type de représentation (voir planche 3), sur laquelle peut se superposer une piste synthétique, doit apporter une meilleure appréciation des conditions de vol.

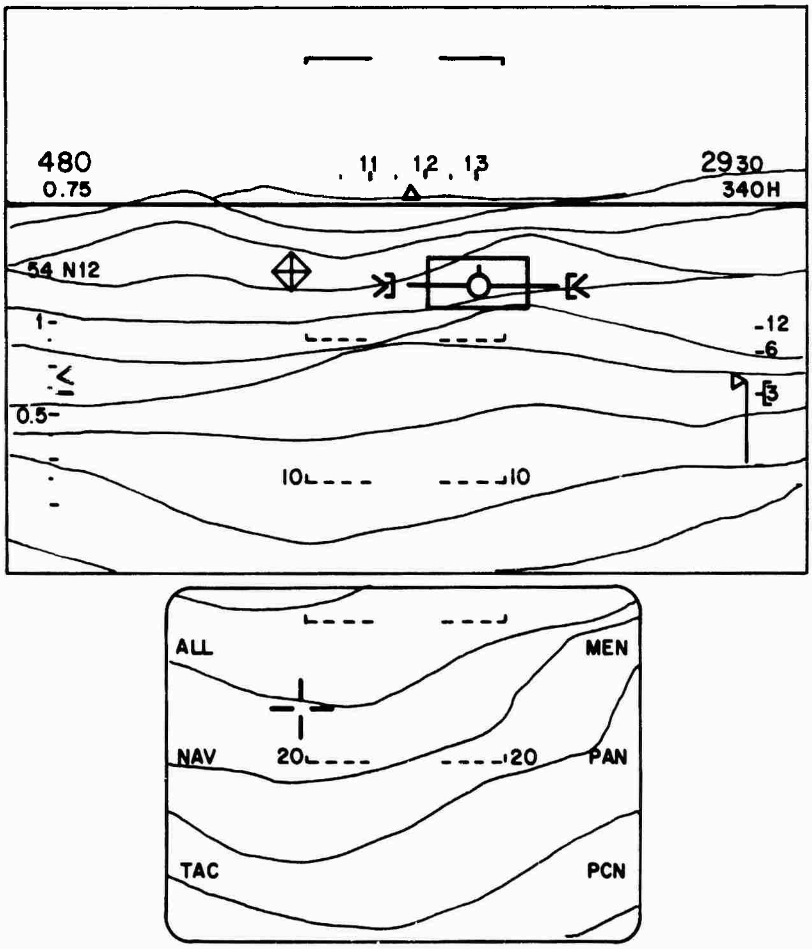
* L'exactitude de la superposition sera évidemment liée à la précision de la navigation.

5.2 - Utilisation VTB 1 focalisée à une distance fixe

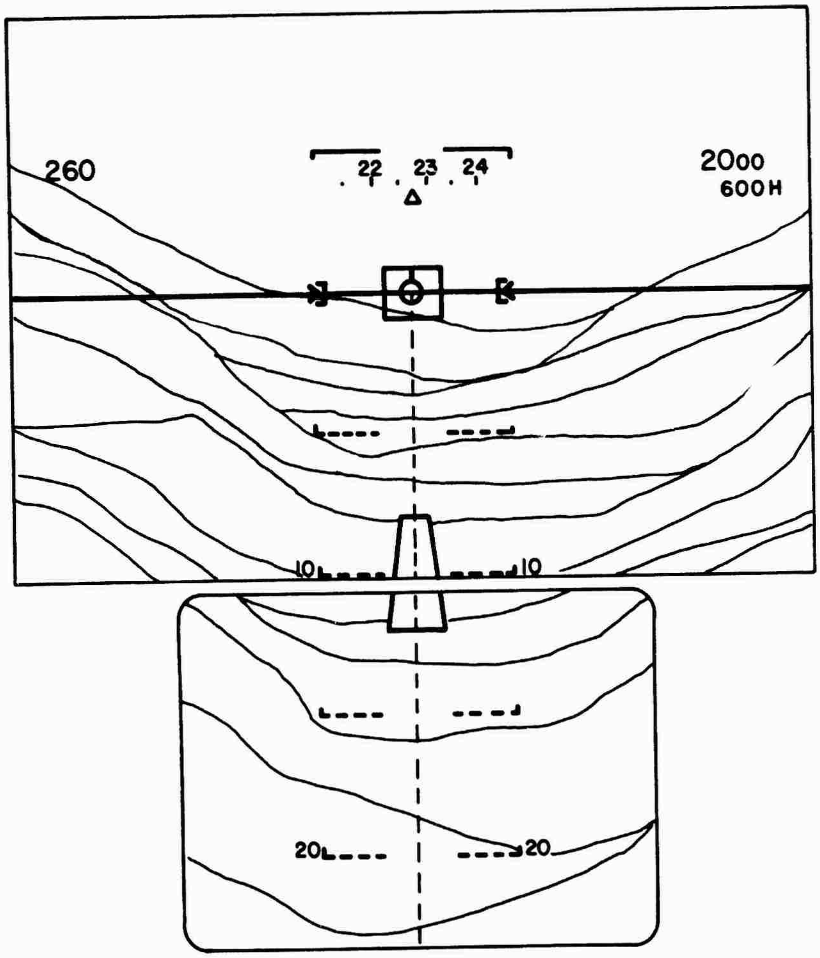
5.2.1 - Attaque Air-Sol

Le combiné de visualisation peut être utilisé en tête basse pour faire de l'attaque air-sol.

Le viseur présente alors une imagerie spécifique air-sol.



VOL TRES BASSE ALTITUDE



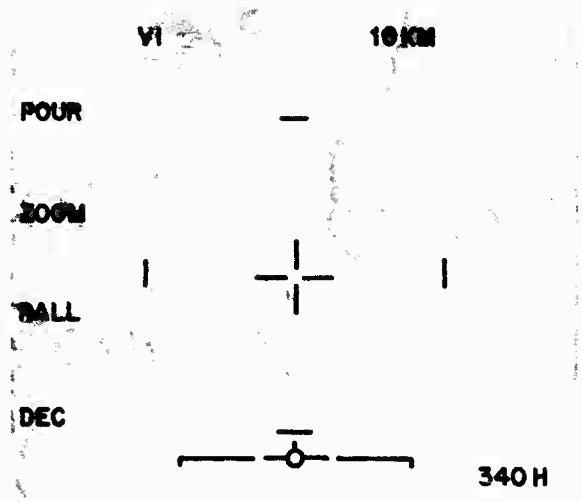
APPROCHE

Planche n° 3

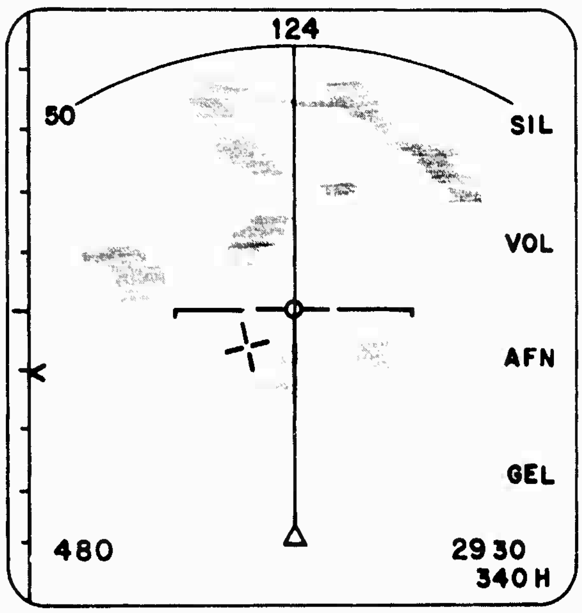
La VTB1 présente l'image d'un capteur optronique, comportant un marqueur de désignation dans sa vidéo.

La VTB2 présente l'imagerie radar en fonctionnement cartographique (visualisation du sol).

L'imagerie élaborée par le radar, utilisé alors en détection de cible terrestre, permet à l'aide d'une alidade incrustée dans la vidéo, de désigner l'objectif et de fournir à l'équipement optronique la direction de pointage ; cette direction est matérialisée par la position du marqueur de désignation sur la VTB1, marqueur qui aidera ensuite à la poursuite de l'objectif.



VTB1



VTB2

5.2.2 - Utilisation en poste de commande

Dans certaines phases de navigation où le pilote a le temps de consulter et éventuellement de modifier le plan de vol, la VTB1 peut-être utilisée en poste de commande de navigation tandis que la VTB2 présente la visualisation du plan de vol.

Le viseur présente alors une image de type navigation, telle que décrite au § 5.1.1.

En VTB1 ne sont alors visualisés que des labels ou des compteurs servant d'interface avec le SNA, les labels permettant des sélections de mode de fonctionnement visualisés en VTB2, les compteurs présentant des comptes-rendus d'actions effectuées sur VTB2.

6 - CONCLUSION

Dans le contexte de poste d'équipege futur meis eussi d'ores et déjà, l'installetion d'un combiné de visualisetion doit permettre une meilleure "rentebilité opérationnelle" des équipements de visualisetion.

Mais il est certain que son efficecìté sera emélioréе par le développement de concepts nouveeux tel que le génération d'un terrein synthétique visuelisé en tête haute, le plenche de bord trensperente, de technologies optiques nouvelles telles que les optiques à éléments holographiques.

DISCUSSION

P.Currier, US

Is the integrated head up/head down system you have described something you have developed, you are developing, or you would like to see developed?

Réponse d'Auteur

Le combiné de visualisation est un système actuellement en développement chez THCSF. Cette société nous a déjà fourni une maquette afin d'effecteur des essais d'intégration. Toutefois cette maquette ne correspond pas exactement au système présenté lors de la conférence, notemment quant aux performances, (problèmes d'encombrement, de volume).

M.Burford, UK

While the proposed IDS solution has certain ergonomic advantages, does not the necessity to rake the pilot's seat backwards, combined with what appears to be a rather large inflexible unit, have a detrimental effect on the forward vision, in particular, in high angle attack attitudes, typical of the landing mode?

Réponse d'Auteur

Aux grands d'attaque typiques du mode atterissage, la compensation de la perte de visibilité vers l'avant se fait en utilisant la partie tête haute du combiné collimatée, ce qui permet d'obtenir une extension du champ viseur "artificielle" vers le bas et la présentation d'une piste synthétique (voir planche Approche) restituant ainsi la vision vers l'avant (concept de planche de bord transparente).

W.McKinlay, UK

Has it been possible to measure the pilot's eye activity going head up to head down with today's displays so as to establish the difference using a collimated HDD? Will the new display influence the amount of time spent heads out, perhaps by being more compelling? Will it have any unforeseen effects on pilot/performance?

Réponse d'Auteur

Il a été établi avec des pilotes, par dialogue avec eux, un besoin de visualisation proche du HUD et rapidement exploitable: une proposition de collimation du HDD nous a semblé être une réponse à ce problème, réponse concrétisée par ce concept de combiné. L'utilisation d'un tel équipement devrait pouvoir répondre aux problèmes que j'ai soulevés lors de mon exposé mais il est certain qu'il offrirait certainement des possibilités d'exploitations nouvelles des visualisations.

Il est probable que son utilisation changerait la perte du temps passé actuellement en tête haute et en tête basse, dans le sens d'une augmentation du temps passé en tête haute (en utilisant le HDD collimaté) mais ceci ne pourrait être confirmé que par des essais au moins en simulateur de vol.

AD P002846

GUIDELINES & CRITERIA for the FUNCTIONAL INTEGRATION of AVIONIC SYSTEMS with CREW MEMBERS in command

by

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SUMMARY

Significant technical hardware advances have been made during the past few years in digital-micro-technology that have caused problems of how to handle and how to use their great potential for the best benefit of designing a distinctly better system and working environment for the crew member in order to make him a real functional member of the system. Such a good approximation to a real Functional Integration of technical means and human beings seems to be the only promising way for a distinct improvement of weapon system effectiveness.

Although the human member of the airborne system has not made at all comparable performance advances, he is increasingly used in a Superman role, required to integrate and monitor most of the subsystems, and thereby to compensate for the shortcomings and discrepancies of the total weapon system. Last but not least the primary job is to perform a mission in hostile environment.

These problematic facts have, in the main, been recognised, but from quite different aspects, depending upon company and country, and upon the personal background/history of the respective manager. Consequently, the results of the respective conceptual and developmental approaches differ considerably. Another aspect which confuses the situation is: everyone seems to be right, because, he is in a position to substantiate his thesis by figures of pilot's workload, system effectiveness and so on -all based on tests and computations. The main reason for the contradiction between Cockpit reality and the assessment thereof seems to be: everyone is right within the boundaries of his approach and in accordance with the Guidelines & Criteria he has used, thus ensuring they do apply.

The continuous discussions about the contradictory conclusions drawn out of operational experience and some attempts of substantiation by strange theoretical arguments reveal an unsolved problem of vital magnitude. This problem can probably only be solved, if it is not treated any more like an one-dimensional/two-dimensional task: Technical means plus human physics. Therefore, we shall try to leave the current pattern of thinking and find out of what nature the factors/influences of the problem are. There will be certainly also factors of mental or philosophical nature, of wrong inference, of aspects and a kind of mixture of several above mentioned influences. A wide field is left for the exploration of the multi-dimensional functional interactions of all these interdisciplinary factors.

The intention of this paper is to provoke new aspects, the designer might need to look at the problem of proper functional integration of man & technical means. Therefore it sketches briefly the operational and working environment for the crew, discusses several different system approaches, and attempts to describe some of the main aspects, guidelines and criteria obviously used therein. Finally a draft of Guidelines & Criteria is proposed for discussion within AGARD, whereof an important element is the proof, that an information or a control is absolutely needed for flight safety or survival.

1. INTRODUCTION

This decade is witnessing a revolution in the design requirements for integrated & automated airborne avionic systems, a revolution whose high ranking goal must be, among others, to develop a man-machine interface, tailored most perfectly to the needs of the human link in the different loops. The latter requirement is the main subject of this paper in the functional sense. In other words, this does not mean a physical tailoring to the human body and his biomechanics, combined with a perfect interior design. This physical portion of the Functional Integration shall not be neglected, but it should be given the place in today's complex system development, that it only can claim: A supporting function at the pilot's side of the instrument panel. Systems ergonomics, only applied at the pilot's side of the instrument panel, is history for a few decades!

This paper is therefore mainly concerned with what is behind the instrument panel. It deals merely with the search for a most human/intelligent functional matching of two "dissimilar organisms", human brains & reactions on the one side, and technical means that can perform some functions like sensing, mechanical actions and even thinking to a certain degree, on the other side. The aim is to find a way to match both "partners" in such a way, that both, jointly in a coordinated and complementary operation, perform together at least one order of magnitude better than each of the two alone.

This paper is furthermore an attempt to underline the importance of the first few phases in the progress of the Systematic Software Engineering, and to show the aspect-derived philosophy used in order to identify the characteristics and nature of the problems to be solved. This paper, however, does not devote a single paragraph to computer languages and/or algorithmic approaches. This will not mean that these tools/vehicles are not important for the development of a complex system with good Functional Integration. For this goal, it is of paramount importance to do the first few phases of the Systematic Software Engineering as carefully and substantiated as possible, up to the phase of the Functional Specifications. They must be oriented towards an optimal compromise between the required systems performance and the technical possibilities on the one hand, and the constraints imposed by the mental and physical characteristics of the human link on the other hand.

The expression which best describes the airborne systems Functional Integration is "Man-Computer-Symbiosis", named by J.Hopson, W.Zachary and N.Lane in 1981,(2), because both, the crew and the aircraft have literally to live with each other.

Isn't all that already incorporated in various of the new first generation aircraft with micro-digital avionics with the MFD's and MFK's ? Don't they have "SOME KIND" of integration and automation? Aren't they all praised as big achievement, called "break through's, watersheds, quantum jump's" and so on ?

As a matter of fact, they all are the result of different attempts to make optimum use of the new digital technology. And they all have remarkable merits, but they also have created some new problems, more or less compromising or even reducing totally the effect of the merits. This paper is therefore also trying to direct the attention to problems, which arise due to inappropriate software engineering of vital functional integrations, that can materially worsen any intended improvement of the system effectiveness. This applies to the kind of integration as well as to the kind of automation. This "SOME KIND" is the problem, with the respective priorities among the functions and the kind of functional interactions! Just modern hardware technology alone does neither make automatically a better system, nor will the better system derive from endless discussions about the computer language to be used. It must be said once more, that the quality of a complex system is mainly determined during the first phases of the Systematic Software Engineering up to the Functional Specification !

Enough possibilities are left during the following phases to worsen the quality of the system. But those possibilities for producing shortcomings and performance degradations are not of a vital magnitude anymore, once a good Functional Specification exists, although the possibilities are still very numerous and manifold!

1.1 NON-TECHNICAL FACTORS and the IMPORTANCE of their INFLUENCE

After the brief mentioning of the main topics of this paper, and the attempt to explain their nature and scope, it should be said,that this paper will also try to stir up some new aspects/interrelationships, which possibly have never become evident before. There is even a high degree of probability, that numerous real critical problems/combinations of factors and the manifoldness of their nature have not yet been identified at all. In no case, is this paper intended to provide "cookbook" recipies !

The scope of vital factors/influences is multidimensional and therefore of a highly interdisciplinary nature. The complex interrelationships cannot be fully understood by simple linear thinking (cause-effect), a method we usually apply. Probably a large portion of the intricate complex interrelationship is already identified, but scattered in small pieces over some hundreds of different human brains, without any interconnection & coordination, a real challenging job for a top manager! The aim of any manager's work in the area of functional integration must be to completely inventory all respective know-how, in order to integrate these bits & pieces into a homogeneous entity that meets the specification.

The specialists for structures, avionics, propulsion, aerodynamics, aeromedicine and so on have each their own aspects and priorities. It is therefore the shaping of the airborne system and the degree of its functional integration which makes evident how much interdisciplinary thinking the manager is able to, and what trade-offs & importance/weight he will allow for other disciplines, he is not familiar with. Such a solo-management depends on a series of individual judgements, and the quality of decisions that cannot be corrected. In the next main paragraph, a few typical examples of shaping will be discussed.

Since,in future, the quality of crew and aircraft become increasingly precious; and since their number decreases accordingly, we shall no longer be able to afford their losses, because we need them and their aircraft and weapon system to survive. Not even in peacetime can we continue the risk to ignore a real interdisciplinary approach in an optimal manner, and simply accept losses as being inevitable. Such an attitude of mind is fatalistic, and of vital influence upon the quality of the total system.

This must be emphazised, because in reality an unacceptably high rate of total losses, man & machines occur continuously in peacetime, without any technical malfunction.A leading NATO-officer said, that there is extremely strong circumstantial evidence to suggest, that at least one NATO air force has lost several pilots and new aircraft in recent years because of intolerable increases in workload at critical times (Robinson, B.L. 1981 (1)). In some cases even highly experienced pilots were involved.

This refers also to aircraft with micro-digital avionics. For a more realistic impression of the circumstances, under which the intolerable increase in workload occurs, you should try to put yourself into the pilot's position in the cockpit,flying 100 ft. high in bad visibility,trying desperately to update the Nav/Attack system, to make the weapon selections, to interprete and react to threat warning, to operate communication, to locate & recognise targets and to stay in formation all at the same time. In addition, the pilot is simultaneously exposed to heat, noise, discomfort in turbulence, sweat, excitement and the grip of fear, all of which will have a detrimental effect on the mental and physical fitness of the man in the cockpit.

Keeping this dramatic situation in mind, who would dare to go on with the current practice to blame the pilot when something went wrong in a mission? Because it is quite easy to note human error/failure, when he missed one control action out of some hundred in his handbook/check list, or mixed up the sequence, the real cause will seldom be found. The following Figures show symptoms of the helplessness in the field of functional integration of humans and technical means in the sense of symbiosis:

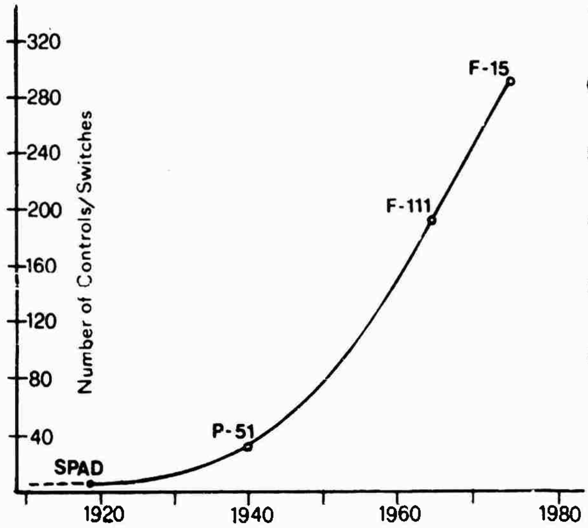

Fig. 1: Number of Controls/Switches per crew member for 4 aircraft: SPAD, P-51, F-111 and F-15. (Source: AGARD Conference Proceedings No.312, Aug, 1981)

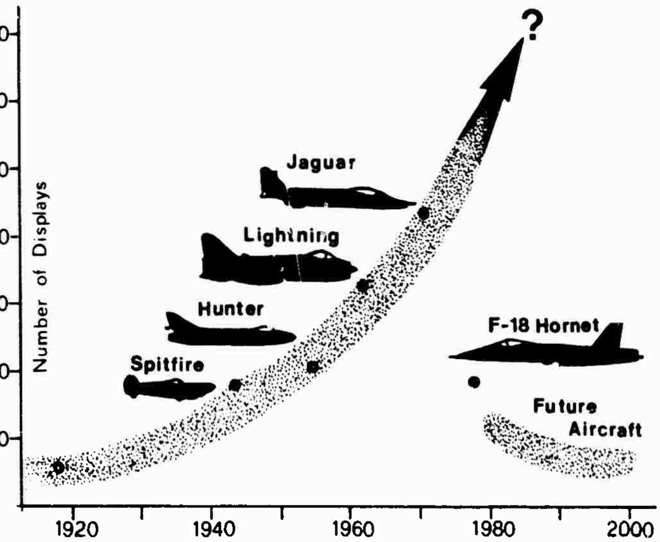

Fig. 2 : Growth of Cockpit Displays (Source: AGARDograph 255, p 12-22)

The facts described and shown above present a phenomenon which is not brandnew. But these facts/factors/interrelation-ships, and the interpretation of their symptoms will have a brandnew quality when they are not interpreted any more as mainly being of technological nature, or simply human error.

The fatalistic production of work overload, imposed at critical times upon the pilot, should mainly be blamed for operational incidents. Is it really enough to talk about the "reduction" of workload and to do only some partial integration in limited areas, while the number of subsystems and their dedicated indicators & controls grows faster than any total integration? That's not really a working concept, as the above described operational experience shows.

The full and appropriate use of today's state-of-the-art technology is, with the design methods known today, mainly limited by the human potential of comprehension of the given information, the proper decision making & the human fitness potential of physical & reflex reaction for control inputs. Last but not least, the full use of the technological possibilities is also limited by the "operator's" actual level of confidence in his ability to perform all these tasks. We cannot change the man. Proper training would help, but never enable him to cope with the overload of the high volume and rate of information presented to make the necessary high quality decision in a matter of seconds.

A dangerous and obstinate misinterpretation seems to persist in most corners of the military avionic world, saying, that the pilot/crew should be kept busy to an undetermined degree of activity, in order to prevent loss of competence/proficiency & the development of complacency and/or boredom. It might be possible that the source is the paper of Curry and Wiener (5), published in 1981. It must be stressed here that their findings apply only to medium/long-range transport flights in peacetime, as is typical for commercial airliners, for example!

The development of military aircraft systems, however, needs a different systematic and methodically substantiated way, which provides an optimum of potential technical means to compensate for man's inherent disadvantages in today's combat environment. This means, we have to endeavour carefully and soundly in order to find optimal ways for the most intelligent use of available technology, we are capable of.

Bernhard A. Kulp said in 1982 (6) "Perhaps we'd better relieve the pilot of some routine task of trajectory and attitude control (and systems monitoring) so he can turn his attention toward targeting, weapons delivery and survival." This kind of thinking is oriented towards a rider on horseback. Although we know about the science fiction character of such an ideal symbiotic interface between two organisms, the orientation sure is right, and we should go as far as thinking and technology possibly allows. This sounds like a Guideline which might turn out to lead to a concept, whose main criterion could become: a MINIMUM of "operator's" workload, instead of only REDUCTION!

2. CURRENT APPROACHES & PRACTICE

The facts described above have been widely recognised, and many different attempts have been made to cope with the complexity of the task by using different approaches of integration and automation, based on different philosophies. The results of those different attempts are also very different, as pilots know by own experience and most developers must admit. Each of these approaches and philosophies has its logic in itself within the boundaries and definitions used for the theoretical or methodological bases, as far as the development has ever been based on something like that. The current, even the latest attempts, however, have one thing in common: they all fall short in the non-technical disciplines, some more, some less. The thinking and working boundaries used do normally not encompass all the main factors involved in the intricate complex interreletionship. The main deficiency is in the non-technical area, the importance that one will allow/attribute to a function, and wether this function should be performed at all. If yes, shall it be performed exclusively by the human link, or by technical means, and according to what criteria shall such a decision be made, if it is'nt predetermined by tradition anyway. Whatever the result of these considerations, only a few cases have become known where old traditional pilot functions, associated with high workload, have been taken into consideration for proper automation, including an assessment of the degree and type thereof (... tailored most perfectly to the needs of the human link in the different loops!).

The normal case is proliferation of functions for the pilot, additional functions in order to compensate for shortcomings of the "technical partner" of the system, caused by the lack of a conceptual methodology, which provides also for the inclusion of the development of "non-technical" functions, performed by technical means. A comparison of the different degrees of automation for mission effectiveness due to unloading of the pilot is certainly of high interest.

There are Top Down Approaches, Bottom Up Approaches, and combinations of the two towards automation and integration, based on different philosophies. Some have no name for their work, they use just common sense, without being prisoner of a theory or systematic procedure. But some special results look like real piecemeal approaches, addressing only single subsystem without considering the overall human member functions, or the implications of other automated systems interactions, using the "philosophy" of proliferation of components, all being integrated by the human link. Exactly Superman's job description!

The distinct decrease of displays for Future Aircraft in Fig.2 should also be a self-evident development goal for the number of dedicated controls, shown in Fig.1. Again, this requires orientation of thinking toward the horseback rider. A horse is a perfectly integrated and automated "CRAFT" !

The science fiction vision of the "man-horse-symbiosis" is certainly not properly placed under a headline of "current practice". It illustrates the distance, however, to some of the current approaches sketched briefly hereafter. Supposedly the following Cockpit-caricatures -referring to the central/vital part of a manned airborne system- are mainly conceived and developed for the same/very similar tactical requirements. Their characteristics,however, are sometimes as follows:

1. The interior designer type believes in hardware with a nice front in the cockpit. The interface-function between man and machine is mainly of optical and haptic nature. Nice to look at, legible and very handy. Besides these main subjects,he reluctantly admits there is also a little noise, heat, vibration and others, all of minor importance. That's all what he knows about ergonomics and their considerable impact on systems effectiveness. Therefore, he looks at the problems as the most practical and nicest arrangement of the controls and indications/displays within the available space of the cockpit. MFD's and MFK's are welcome because they look modern and they bring about a relief of the "real estate"-problem in the cockpit.

   The interior designer does not ask, whether all those control-inputs and indicated/displayed informations are necessary, usefull and right, or how much workload they put on a man in a critical mission phase, while he is also very busy, incidentally, to fly a mission.Complex systems interrelationship and the appropriate software is something mystical, and therefore other peoples business. To him the interdisciplinary range is limited to the cockpit interior, biomechanics and the personal comfort of the crew.

2. The electronics freak-type uses the most modern -even immature- electronics. His system is the maximum of any possible sophistication among all others. His electronic world looks bright and clear, when he can present his creation to show all the dazzle of his light and sound spectacle. He will produce an information rate and volume of such magnitude that the crew members become unable to cope with it, in a real airborne cockpit.

   He is proud when visitors are amazed or confused -he does not realize the difference- about the incredible span & scope of electronic possibilities and variations thereof. He plays masterly with hundreds of buttons/keys and controls and seems to have three/four hands, because he can simultaneously point to lights, indicators or other events which appear/happen as a result of his finger activities, according to his explanations.

   In case, one of the visitors really understood what happened, and comes back a few weeks later, almost everything is different, and the explanation will start all over again including light and sound.

   One day the development must be frozen and the users, the pilots, shall learn several hundreds of pages in the dash-one-handbook plus the simulator and cockpit training hours, weeks, month....

   When such an aircraft crashes one day, this case will be listed under attrition rate; observation: human error/failure !

3. The old war-horse type-cockpit maker does not give very much thought to the workload producing non-automated functions. For him simply the nature of workload has changed from the real face to face and almost physical fighting with Spitfire's,Mustang's, Messerschmitt's to the kind of mental workload associated with modern technical means. This type of gear requires information absorption, interpretation, decision making and action/reaction, -without seeing the adversary. He is damned right! It is our problem to cope with the fundamental change of the nature of workload. The attitude of the war-horse type toward workload is: The job must be done, and can be done, provided proper training and enough warriors are in the planning.

   He admits that there is an interaction between workload and systems effectiveness. In case the workload appears too big to him for a single man, his simple conclusion to get out of this situation is to divide the workload between a two-man crew or more.

While thinking everybody is doing his part, without a too heavy burden of a workload, he could not be more wrong, for, in reality, this has nothing to do with job sharing as it is practiced in industry. What the two man of a crew really must do, is the performance of complementary work elements. These elements, however, do not give the prerequisite of the necessary functional integrity, when performed individually.

The high quality decisions necessary within a severely restricted time frame are only possible, when these elements are done simultaneously and every one knows at any time what the other does/intends to do.Such an interrelation requires a mental and functional matching of two (or more) "similar organisms", an additional person-to-person interface! This interface brings with it all associated problems, so as to obtain a complete and smooth information flow in the man/man system. This applies especially when the two have the same strong personality, or each one is used to different thinking patterns.

A real objective comparison between the above parodistic description of three different attempts for a functional linkage/integration of two "dissimilar organisms" to a good approximation to the goal of "man-machine-symbiosis", is not possible. But there is a short list of things worth to be mentioned. This list does not claim to be complete nor to be in the right order of priority by importance/vital influence. The list intends only an initiation of a possible extension of considerations as to aspects, completeness of factors/disciplines, and the degree of influence they might have upon a multidisciplinary system. Therefore it could be, for example, a very important result, when those considerations about the process of the development approach, either lead to the exclusion of a factor/discipline, or only to the attribution of minor importance because of no or minor influence.

I am certain that neither myself, nor some one else will have a complete set of noteworthy topics hereafter, and no valid answers either. In order to get some more substantiated methodology, the USAF works with other services since 1981 in this vaste interdisciplinary area (6), and plans to do so for five more years.

But we all know the topics exist and good answers, as to the degree of its vital influence, are very important, because they form the prerequisite for good software, which we desperately need! We urgently have to catch up with the increasing performance potential of the hardware developed, for its full and appropriate use! The paramount hardware potential makes only sense when the software gap will be closed soon and firmly.

The before-mentioned sketches of cockpit types have -besides their differences- several things in common:

- they all put their main emphasis/priorities on different factors out of the interdisciplinary multitude of disciplines and their parameters, their mutual interaction and the resulting effects.
- they all have different guidelines & criteria for the concept and for the assessment of the effectiveness. Objectively, they have very little in common -exept some similar instruments and shortcomings.
- they all demand more or less a different mixture of work overload from the pilot at critical times/phases of the mission. (see page 4, last para.)
- the hardbooks for the crew contain all but brief & clear instructions for the proper use of the system in the different mission phases. Mistakes/"human errors" are preprogrammed.

- none of the cockpits represents a good possible approximation to a fully conducted attempt of an interdisciplinary approach, taking for example the human member fully as a complementary part of the total system, performing only in the functions/roles in which he excels, problem-solving/decision making, e.g.
  The human member, however, is mainly required to struggle in a double role:
  - compensate for the lack of proper data/information processing & integration
  - cope with a collection of complex activities which were not understood well enough to automate

  In both roles the human being does not excel !
- Guidelines & criteria with even identical phrasing, but written by different people, are, when applied to different cockpits, not comparable, because they use different definitions, different priorities and they are measured by different methods.
- The usually dictated requirement for employment of existing hardware -whether airborne or not- predetermines once and for all the avionics architec-ture, multiplies the technical interface problem, dictates one or more computer languages, and some other vital performance reductions, as compared to the technical and budgetary possibilities.

The commonalities list, in reality, is much longer! It is to be hoped, however, that this type of commonality will not become a kind of STANAG-status.

A good reason to believe in a different commonality are the first signs, which allow to believe that some flying machines seem tentatively to help finding a better understanding of the necessary elements & their interrelation for a good approach to the functional integration.

2.1 NEW AIRCRAFT & NEW INTEGRATION APPROACHES

a.) Hardware

One of the best known aircraft, where a consequent functional integration has been attempted by means of digital avionics, is the F-18. In this aircraft, one of the symptoms for non-integration, a high number of dedicated indicators/displays, has been reduced significantly as shown in Fig. 2.

As to the corresponding quantity of controls & switches, a figure to be put in Fig. 1 is not known to the author of this paper. There is good reason to believe that the number of dedicated switches & controls has been reduced also by means of integration and automation of functions.

No one can say, how far away the F-18 is from a possible optimum. It sure is a big step in the right direction. Other aircraft development with/and integrated digital avionics retrofits are under way. A comparison of the different approaches is not yet possible, because either the aircraft with their avionics are still in the development phase or the retrofit kit has not yet been adapted to the aircraft. Other various reasons do also exist.

It should be stressed here, that the revolutionary phase we are presently in, is marked by the search for the best way to cope with the paramount potential of the new electronics. It should also be stressed that an increasing percentage of the people who have to deal with its unexpected possibilities become aware of the miraculous nature of this dangerous toy, and its problems. The euphoric phase is over. Assuming that several different aircraft with different avionic/man integrations are ready for assessment & evaluation, the comparison will remain impossible. One simple reason prevents a valid comparison: the lack of common yardsticks/criteria and methods to measure, especially for systems effectiveness of military aircraft.

b.) New theoretical approaches supported by experiments/practice

In the last paragraph, this paper will help to initiate discussions for the preparation of such criteria which will assist to improve the quality of a functional integration by means of appropriate development priorities/objectives/interrelations as well as to make these measurable, and thereby more objectively comparable.

In addition to the direct development of hardware with the appropriate new kind of software, two projects are in progress and seem promising regarding future approaches for the optimization of systems effectiveness.

- Reference 2 describes a combination of Top Down & Bottom Up approaches actually worked on in the US-Navy to develop Decision Aids for multi-crew aircraft such as submarine hunters, sea patrols etc. This activity is part of a DAS program (Decision Augmentation Systems).

  The title (The intelligent use of intelligent systems....) indicates the direction where it comes from: The computer people corner, aiming at the support of crew members who have to process a large amount of information and data, whose source is a multitude of dedicated instruments, sensors, subsystem outputs,control position or force and other crew members. They aim to alleviate the critical workload of TACCO's & other crew members.

  Direct functional action like automation of trajectory/attitude control, target tracking, fire control, weapon release or others seems not to be intended within the frame of this approach. This limitation seems to exclude the physical part of the symbiotic partner, the man, as well as hydraulics, electrical drive, propulsion.....

  The reason that makes this approach promising for the mental part of the total system, is the practice-oriented methodology of the Systematic Software Engineering process which attempts to come close to a complementary/symbiotic work-type of both man's brain and computer. In addition, a high degree of realism seems to be assured by taking into account right from the beginning existing hardware facts and human perception & processing capabilities.During the combined process of Top Down & Bottom Up approach, the permanent reference to reality is maintained by means of practical tests.

- Reference 6 to a high degree is a TRI-Service activity which began in summer 1981 where USAF is the lead service. This program, with the objective to develop a series of specifications and guidelines as to what functions should be automated and integrated to an appropriate kind and degree, comes obviously from the practical users corner. It brings about the realities of man's inherent shortcomings in using sophisticated systems,especially in critical mission phases. The basic information herefore is gained by means of a systematic interview of a large group of all kinds of pilots. A methodology is than derived from this data basis,written down in a report of the National Academy of Sciences.

  This report shows a scheme to the air force which it can use to look at its programs. A five year work has begun to develop and substantiate the above mentioned series of specifications and guidelines. This work is oriented towards the assessment of aircraft control functions to determine the order in which functions should be automated and subsequently integrated with other functions.

  This program is a very promising complement to the approach of Reference 2, because it seems to bring about most of the non-technical elements which are necessary for the functional integration of man & machine. It is a kind of systematic six step process that introduces the non-technical factors, some of which are to be derived from the different mission phases in the combat theatre. Some others stem from the variation of human factors during the mission and deal with flight control, autopilot, target sensing & acquisition, navigation, propulsion control, external data input, crew station, threat warning & countermeasures, weapons delivery/fire control, fuel management, malfunction warning.........

It will enable the developer of functionally integrated avionics to write a realistic interdisciplinary Functional Specification which is of fundamental importance !

The attempted mental symbiosis of Reference 2 seems to be restricted to brain & computer. A combination of the two approaches (Ref.2 plus Ref.6) encompasses the whole man and the whole aircraft to a systems entity. This is what I mean with the parable of the "man-horse-symbiosis", where both are functionally integrated with each other during a ride, by means of a perfect interface. The information fed through this interface is a minimum of touch, word and tender pull of bridle, in the direction from man to horse. The information from the horse to the man is mainly fed by its movements (direction & speed of run...)and, of course, by the voice and its breath too.

All other functions of the horse are automated and integrated. The rider does not monitor data, such as temperature, blood pressure, heart beat......

His workload is not only reduced (like everybody requires), but minimized, and therefore his perception, processing and decision potential is free for the mission!

3. Draft Proposal: Guidelines & Criteria

As a conclusion of the above mentioned description of interrelations between the different technical, military, geographical, seasonal, tactical and human factors, a radical change in thinking is dictated. Old and current thinking patterns -without any serious consideration about their applicability- will restrain the necessary interdisciplinary span of the approach, and will prevent/reduce the possible progress toward the potentially significant increase in systems effectiveness.

An unconventional and independent thinking is necessary and shall cover aspects such as:

- extension from a limited subsystem thinking and acting to overall systems functional interrelation thinking.
- inclusion of the human link functions (including integration) and characteristics in the overall functional analysis and specification of the total system, before assigning priorities to the automation of functions.
- aspect change of the machine-oriented operator-role of man, to the man-oriented tool/ support-role of the technical means (hardware and software)
- strict matching of subsystem thinking within the frame of the total system, in order to avoid mutual "retrofit adaptation", due to isolated subsystem development.

According to the above man-horse-parabel, and without any possibility of proving it at this time, the author would like to postulate that the pilots/crews workload not only has to be reduced but minimized ! This postulation is additionally supported by pilots experience according to Reference 1. Incidentally, the author has some 20 years of flying and flight test experience too.

The following Guidelines & Criteria are established with the minimizing-premise in mind, for military manned aircraft.They apply primarily to single or two crew aircraft which operate mainly in or close to the combat theatre, and which must perform many tactical maneuvers. They contain keywords and determine thereby the criteria within the concept for the design process and the assessment thereof.

a.) Guidelines

1. The man-machine interface schall be considered a highly critical item within the overall systems loops. Accordingly this interface shall be given the appropriate high priority against all other factors unless these taken together are of vital importance and can be justified using criteria yet to be determined.

2. Compromises in sub- and total systems layout and practical design should be confined to the area outside the display & control system in the cockpit, unless criteria yet to be determined justify digression.

3. By no means everything technically possible shall be made or done within the cockpit. This applies to the presentation of visual, acoustic or haptic information and combinations thereof as well as to the provision of any kind of control (switches, levers, knobs, keyboards etc.), which requires avoidable control action.

4. The amount and the kind of information and control functions to be handled by the pilot/aircrew shall be limited to that, which
   a) cannot be improved by automation
   b) is absolutely required for operational purpose
   For any additional information and control capability, the need must be justified.

5. By no means, systems having possibly a cockpit interface shall be specified and developed in isolation, without allowing to be controlled for overall cockpit layout and integrated functional fit.

6. In order to achieve the goal of an optimum in total systems functional integration, including its human member, interdisciplinary thinking and working is mandatory throughout the subsystems design and development process. This is to be ensured by appropriate managemant procedures and measures.

b.) C r i t e r i a

1. Consideration of pilot performance characteristics.
   Pilot performance is characterized by:
   - high variability of mental (information) processing and decision making capabilities
   - poor monitor and watchkeeper capability
   - high variability, however limited speed of motor-capabilities
   - susceptibility to sequential errors where a step is left out of a procedure and capture errors where a familiar procedure is substituted for an intended new procedure.
   - moderate performance in serial processing -A human's attention to two or more activities requires rapid switching between the tasks.
   - poor perception & processing capability for high information volume and rate
   - poor processing rate -Two events occurring closer together than 0.1 sec. generally will be perceived as a single event.
   - little "reconfiguration" capability

   N o t e: All above mentioned capabilities will suffer a considerable degradation in a hostile and/or emergency environment!

   The priorities resulting therefrom are to be accounted for in trade-offs performed!

2. Limitation of information displayed (or somehow given to the pilot).
   All cockpit functions and correlations thereof shall be checked, wether their automation would be advised, in order to reduce the amount of visual, acoustic and haptic information being fed trough the man-machine interface to the necessary minimum. Criteria against which the checking shall be performed are:
   - feasibility
   - pilot workload minimal possible in a combat situation
   - freedom of pilots judgement/decision within systems performance/maneuvres/actions in any mission element

3. Limitation of all kind of control activities.
   All input- and/or control functions shall be checked whether their automation would be advised, in order to minimize the necessary amount of manual or other activities to be performed by the human member.
   Criteria against which the checking shall be performed are the same as in 2. before.

4. Any automated information covered by criterion 2. may be provided for the human link whenever it serves to improve his judging of the flight or combat situation in order

to reduce an unnecessary emergency or threat risk.
A trade-off shall be performed between the degree of risk reduction achievable and the resulting increase in the pilot's workload, taking criterion 1. into consideration.

5. Any input and/or control activity that might be automated according to criterion 3. may be imposed on the human member, whenever an emergency or threat can be covered therewith in the vital sense, which could not be covered by technical means.

   A trade-off shall be performed between the increased probability of overcoming the flight safety or threat risk against the increase of pilot workload, taking into consideration criterion 1.

The above proposed Guidelines & Criteria are intended to offer a basis of discussion for the development of common Guidelines & Criteria within NATO. They are also intended tooffer some aspects and means which might help to find better judgement as to the evaluation of designs, design approaches and with respect to its kind of techniques used to achieve the goal of the different milestones. They might furthermore be of assistance to improve the quality of the key design decisions which must be made at all stages of the development process.

4. CONCLUSION

A main effort of this paper ~~is to~~ advocates a maximum of interdisciplinary work. Accordingly emphasis is put on the need for better functional integration of the human member of the system, and ~~by~~ the minimizing his workload, instead of only reducing it in some areas. ~~Therefore~~ the author proposes to combine the two approaches of Ref.2 and Ref.6, roughly a combination of the mental and the physical part to make maximum use of the human member's unsurpassed capabilities. He is still the main limiting factor for the system effectiveness, due to the inappropriate interface/functional integration with the system's technical means.

Although this paper does present a ~~kind of~~ systematic approach by means of the above combination, the author has no illusion that the development of such an integrated airborne system can be properly engineered now to the possible optimum. Such a work still relies more on "art" than engineering! Maybe this paper is at least a contribution to a more realistic evaluation of the effectiveness of man-machine interfaces.

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NAVY'S ADVANCED AIRCRAFT ARMAMENT SYSTEM PROGRAM CONCEPT OBJECTIVES

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SUMMARY

The Advanced Aircraft Armament System (AAAS) was originally chartered to improve armament equipment performance, support, and interoperability. Because of funding constraints the AAAS Program has been increasingly directed to development of air armament interface standards and technology, while advanced concept development of suspension release and stores management equipment has been de-emphasized. The current program concentrates on supporting the Joint Navy/Air Force Aircraft Armament Interoperable Interface Program whose task is development of MIL-STD-1760 (Aircraft Electrical Interconnection System) and associated guidelines for successful application.

Since the advanced concepts which were to be originally developed are a more appropriate subject for this paper, the context of the discussion is the program prior to the redirection. The Fleet needs and deficiencies which provided the requirements for the concept effort are briefly outlined, the objectives and goals are detailed, and the approach to achieve mission flexibility and performance improvements at reduced ownership costs is discussed. A key aspect of the approach is development of generic designs which capitalize on cost and growth advantages of standards while allowing incorporation of advancing technology.

INTRODUCTION

The Advanced Aircraft Armament System (AAAS) Program began at the Naval Weapons Center in October 1978. Original objectives included development of advanced stores management system (ASMS) and suspension release equipment (S&RE). Initial program goals also comprised armament performance and supportability improvement as well as future aircraft-weapon interoperability. Currently the program has been redirected to emphasize the interoperable interface standards and design guidelines for successful future SMS implementations on fighter and attack aircraft. These interface standards are being developed under the joint Aircraft Armament Interoperable Interface (AAII) Program in cooperation with the Air Force Armament Laboratory, Eglin AFB, Florida. The standards are incorporated as physical, electrical, and logical portions of the MIL-STD-1760. An electrical signal set was released 1 July 1981, and Notice 1 is soon to be published documenting intermateability characteristics of the connector portions (physical) of the standard.

This paper will not discuss the AAAS Program as now chartered, but will cover those original stores management technology objectives and approaches which were to be accomplished and which relate to avionics concept growth.

A Stores Management System, defined herein as an element of aircraft avionic and weapon systems, performs functions which include monitoring, initializing and controlling stores and the associated suspension release equipment. The SMS provides fault assessment, mode regression and jettison backup capabilities. In the past, SMSs have been developed on an aircraft-by-aircraft basis. The older SMSs are generally hardwired, not integrated, not automated, and they embody outmoded technology. Newer SMSs reflect more current technologies and far more effective integration and automation. However, it remains a fact that even modern SMSs are tailored to support the specific stores list and unique loadout configurations of individual aircraft types.

The discussion which follows will explain the source of requirements for improving stores management designs, the resulting objectives, and finally some of the useful concepts which have emerged. The program was active for approximately three years during which time interaction with Fleet users and industry produced a series of technical area reports and a contract statement of work and specification. Currently, two contracts are in place and system analyses have begun that will result in design specifications for an advanced generic system. During initiation of the contracts, an attempt was made to maintain an awareness of the main thrusts in avionics design and integration. Some of the concepts evolved during performance of the contracts may have application to avionics integration or at least may be useful in defining the evolution of stores management for follow-on avionics systems effort.

SYSTEM DEFICIENCIES AND REQUIREMENTS

In the seventies, a number of studies were initiated to identify those functional interfaces between a ship's company, air armament equipment, and standard operating procedures which impact mission effectiveness. The proliferation of aircraft armament equipment was determined to be a significant source of operational and support problems, and it was recommended that aircraft armament system interfaces be controlled in the future to minimize such proliferation.

The initial studies also identified characteristics and functions of the mission cycle which were deficient in capability and required performance improvement. Many of the deficiencies, such as lack of availability and/or selection in weapon systems, impacted numerous elements of the larger Navy Fleet missions; these deficiencies also were directly influenced by aircraft stores management system capability. The relationship of these needs and deficiencies to the carrier aircraft mission cycle is diagramed in Figure 1. Some larger needs, in terms of ownership cost impacts, were those associated with the ability to extend mission capability or service life of existing aircraft by reconfiguration and modification to accept new weapons. With current aircraft and avionic designs, this capability is made extremely costly and limited by the uniqueness of the large number of armament interfaces concerned. An illustration of this interface proliferation is shown in Figure 2. The cost of new weapon installation in older aircraft is so large and carries such large support implications that deployment of new weapons is severely limited.

A further complicating factor has been the growth in complexity and number of weapon types required in modern warfare. Figure 3 shows this growth in terms of numbers of pins at the interface and the large variation in signal types between weapons. A major objective of the AAII Program has been to develop MIL-STD-1760 (the aircraft electrical interconnection system standard), to control interface complexity, and to encourage growth of digital systems in missiles. However, to make future aircraft, whether new or updated, capable of low cost armament growth without major avionic and control system impacts, stores management systems must be designed with absorbent hardware and software architectures.

One driving requirement then for the AAAS and AAII efforts is to improve interoperability among aircraft weapon systems. Weapon system interoperability, as it applies to military aircraft, describes those capabilities of the system that allow it to be used in flexible mission roles in any battle area and over a full system lifetime to make the large capitalization cost effective. Modern military aircraft and weapons are products of the best designs presented at the time of commitment to production and, as such, are point design systems. However, rapid technological advances and changing enemy capabilities frequently render entire weapon systems obsolete—in many cases the day the new system becomes operational. In order to counter the effects of obsolescense, aircraft and weapon systems must be continually upgraded by expensive modifications involving installations of new technology subsystems and assemblies. This very high modification cost and associated time constraint is a major problem again resulting in limited initial procurements, restricted deployment of new capabilities, and resulting high unit costs.

Recently the Department of Defense and Congress has taken a position to encourage the use of standards in weapon systems. A major obstruction to interoperability in aircraft weapon systems is non-standard aircraft-to-weapon (store) and store-to-aircraft interfaces. Other interfaces such as the weapon to avionics, through the stores management subsystem, also obstruct interoperability and growth.

Complexity and proliferation have brought other deficiencies and needs which influence stores management and avionics systems. Most of these involve performance, support, or cost. The more dramatic include pilot workload and training increases and pilot task complexity growth. For the ground crew, the task complexity growth is even greater and the effects appear in downed aircraft and lower aircraft availability. To reach acceptable levels of readiness and capability at affordable expenditures requires improvements in performance and judicious use of standards throughout the aircraft armament system. This of necessity involves the avionics system and its integration into aircraft and weapon systems of the future.

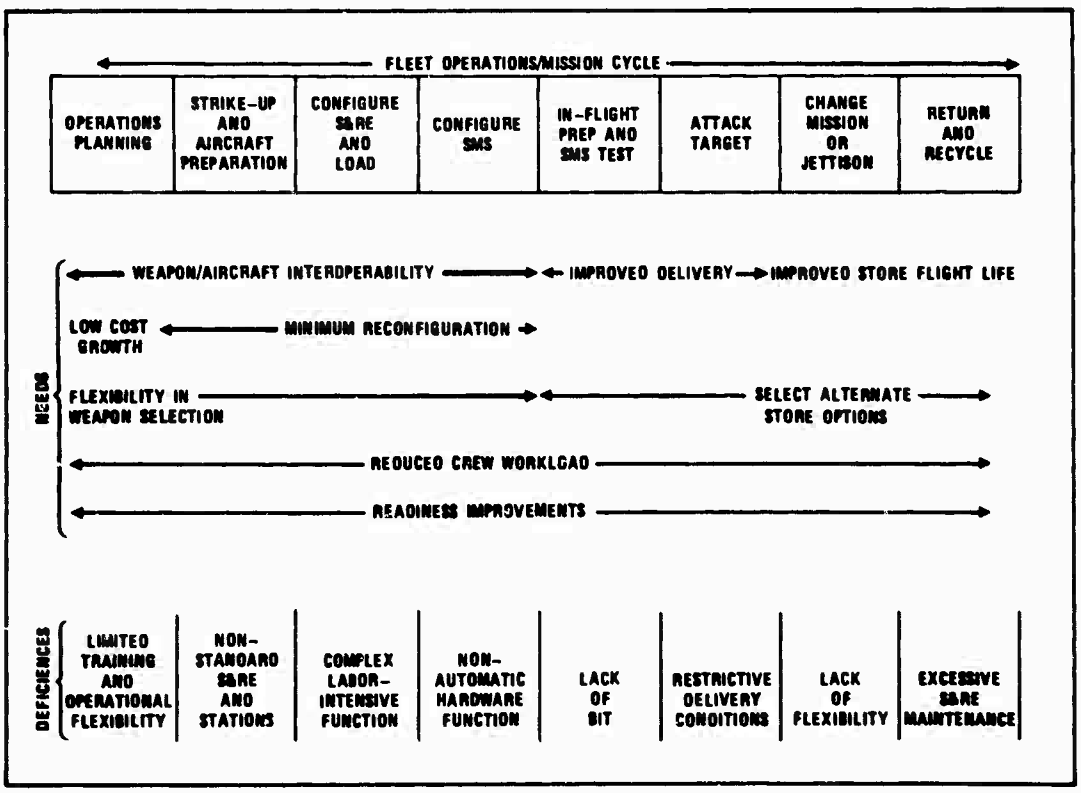


Figure 1. Carrier aircraft mission cycle needs and deficiencies

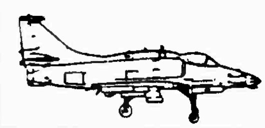
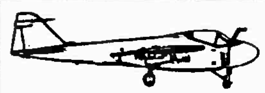
	HUMAN INTERFACES			EQUIPMENT INTERFACES		TOTALS
	SWITCHES	CONTROLS	MONITORS	COMPUTER	OTHER	
	7	10	4	4	24	49
	2	18	5	1	16	42
	4	10	4	3	32	53
	4	10	4	2	21	41
	3	9	3	1	18	34
	3	4	4	1	15	27

Figure 2. Navy aircraft armament interface proliferation

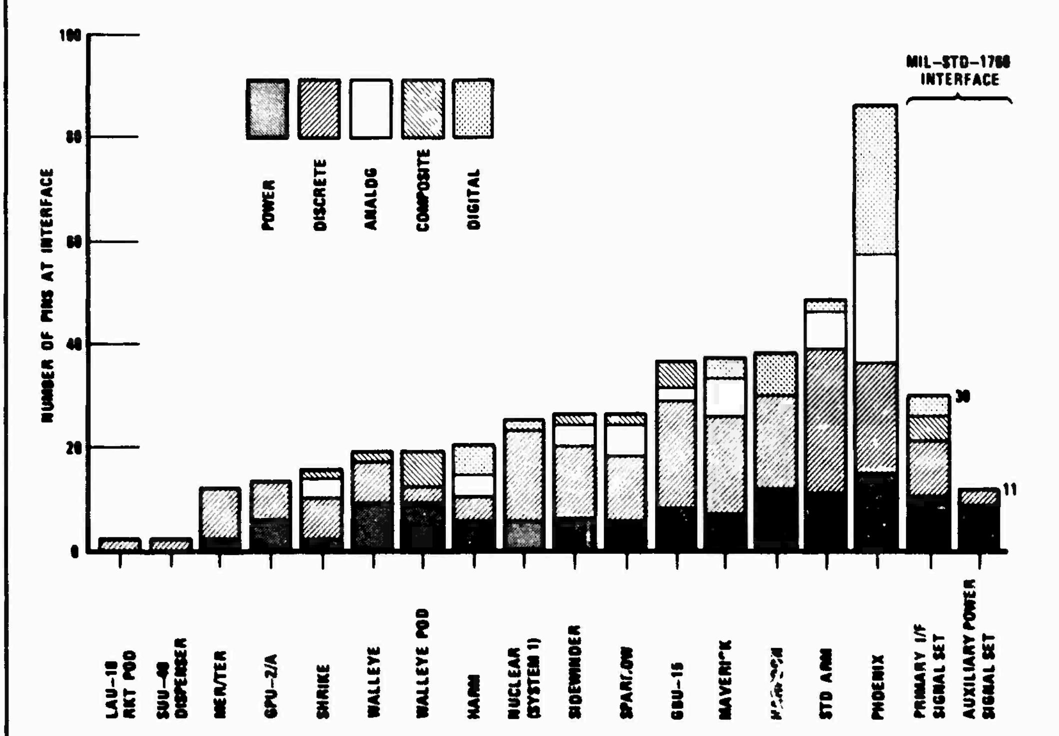


Figure 3. Relationship of growth in weapon signal complexity to MIL-STD-1760 electrical signal set

AAAS APPROACH

In response to these needs the overall objective of the AAAS Program became not only standardization of weapon-to-aircraft interfaces but to do so without restricting technology and design improvement growth. This required coordination with all affected groups to develop interface associated equipment design guidelines for improved performance. These design guidelines would also include standards which it is believed would halt the proliferation of interfaces and help in achieving low cost growth and support objectives (see Figure 4). Although this objective covered suspension and release equipment this paper only discusses the stores management equipment and briefly the standard interface.

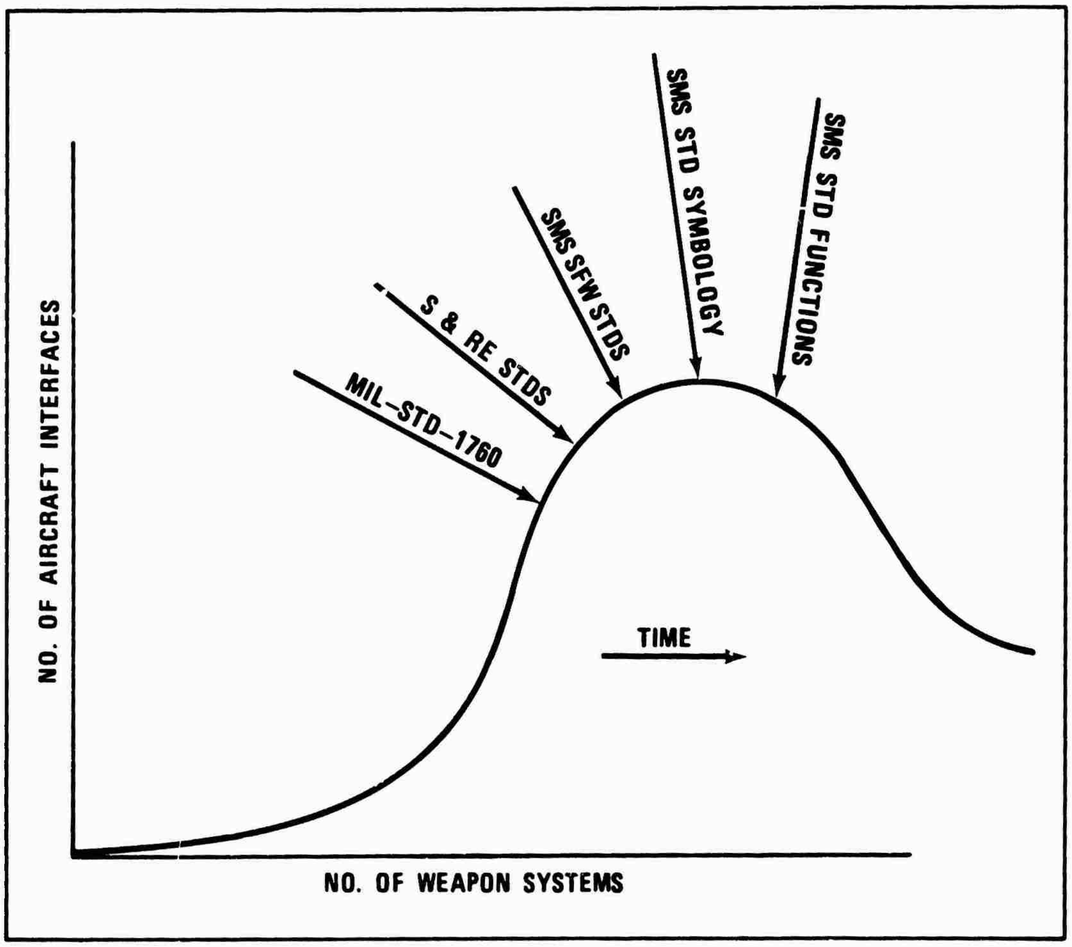


Figure 4. Development and implementation of standards to reduce armament interface growth.

Figure 5 summarizes the major AAAS objective, the required products, and lists the expected benefits and approach. Besides the AAII joint program, a laboratory tool was necessary to investigate options, and test design guidelines and validate standard decisions. The ASMS laboratory proposed, and which is now partially constructed, is shown in Figure 6. This lab configuration requires the development of future store and aircraft simulators and stimulators, an advanced stores management subsystem of a generic nature, and a computerized data base and software necessary to drive the data base.

In the ASMS laboratory, coded data will be transmitted over twisted-wire pair, internal time division, command/response, multiplex data buses which meet MIL-STD-1553 requirements. The control/display equipment will employ integrated multifunction, multicolor displays with preprogramed built-in-test diagnostics and control options through a dedicated control panel. The store station equipment (SSE) will be a distributed family of programmable microprocessors which code/decode message transmissions and process messages to control power switching functions and communicate with interfacing stores. The SSE will be preprogrammable to be compatible with interoperable carriage and mission stores. The central processing unit will be preprogramed for command and control of appropriate mission scenarios and tactical contingency options.

The ASMS laboratory system will be used to control and exercise the MIL-STD-1760 electrical interoperable interfaces, allow development and assessment of future Navy aircraft specifications for SMS, and validate developed armament implementations. The advanced stores management laboratory will include signal control equipment, displays and controls, store station equipment, data transfer equipment, and stores management processor software. Stores management subsystem concepts and alternatives to be validated include: digital data bus architecture between the stores management processor, store station equipment, and the display and control panel; and very high

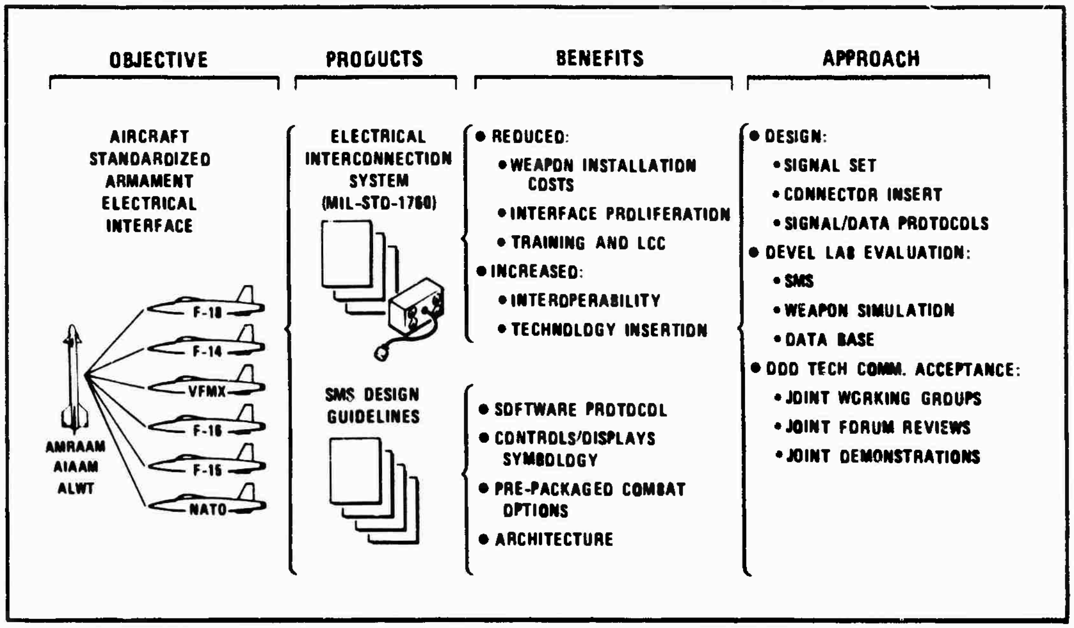


Figure 5. AAAS program essential characteristics.

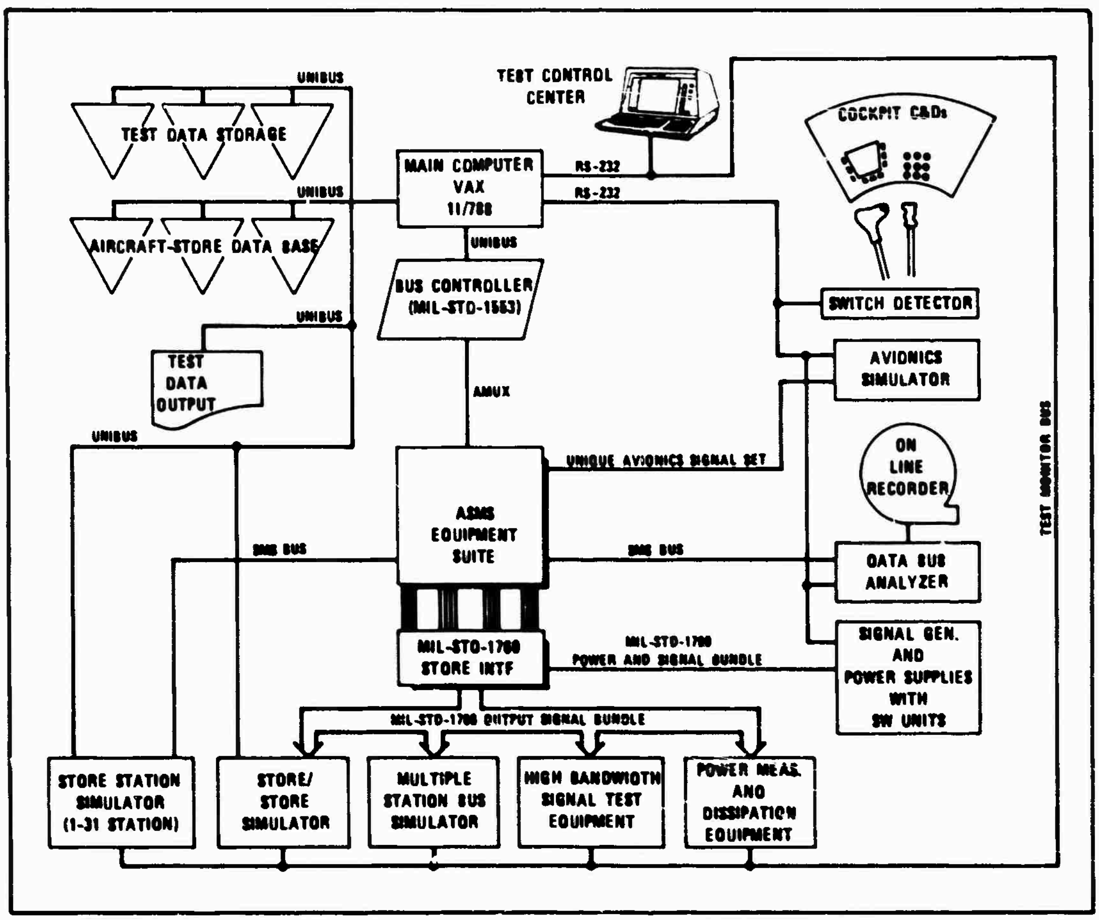


Figure 6. Advanced SMS laboratory for the study of interface and SMS requirements

speed integrated microelectronic devices/packaging for store stations in adverse environments. The ASMS laboratory will also be employed to evaluate stores management equipment architecture optimized for reduced crew workload, subsystem operational flexibility and survivability, and inflight degraded mode operational assessment. SMS programmability concerning the addition of future weapons to an aircraft store suite with minimum cost and time will also be studied in the ASMS laboratory.

A series of contracts were awarded and engineering studies conducted to define:

(1) the signal, states, and control characteristics of future projected and existing weapon systems,
(2) information and electrical power transfer characteristics across the weapon-to-aircraft interface,
(3) obstructions to operability
(4) standardization alternatives as a function of several system characteristics,
(5) generic SMS and laboratory software and hardware architecture options, and
(6) several studies relating to special SMS or interface system problems.

The results of these studies were used to generate inputs to MIL-STD-1760, to prepare the ASMS contract specification, and were also given to industry bidders as background in bid preparation. In order that the joint interface standards and SMS design guidelines efforts would be successful and provide a broader search for engineering solutions, two contracts were awarded, one by Navy AAAS and another by Air Force AFATL through the Navy.

Although the AAAS development efforts are not complete, some emerging concepts may be of interest to the avionics community. These concepts representing only a portion of those developed will be discussed in the next section.

CONCEPTS

The concepts worthy of discussion at this time evolved from the systems analysis efforts directed at defining and evaluating standardization opportunities, rationales and requirements. Valuable concepts were also gained from the ASMS contractors bid responses to the SMS engineering functional requirements developed during 1979-1981. They will be briefly illustrated and discussed in the following order:

Store-to-aircraft standard interconnection system
— obstructions to operability
— operability levels

SMS architectures
— multiple buses and distributed processing
— total aircraft data network
— fiber optic application
— software development tools

SMS subsystem standards
— data transfer
— software
— digital process control
— briefing entry device

STORE-TO-AIRCRAFT INTERCONNECTION SYSTEM CONCEPTS

The development of criteria for assessing interface standards effectiveness and selecting standardization alternatives for MIL-STD-1760 resulted in concepts which may have application at other aircraft and avionics interfaces.

Obstructions to Operability

The first of these concepts is the definition and decomposition to design level of the characteristics which are preventing or obstructing operability at the interface. Although this appears at first glance to be normal design analysis, its rigor makes possible the development of operability levels for assistance in subsystem integration and standards selection. Six of the nineteen obstructions to operability developed for MIL-STD-1760 are decomposed in Table 1 as an illustration of the concept.

Operability Levels

The second concept is the technique of structuring operability levels in ranked order of decreasing system impact top to bottom. This arrangement allows the development and comparison of standardization alternatives for various desired integration objectives or degrees of standardization.

Table 1
OBSTRUCTIONS TO OPERABILITY CONCEPT

Obstruction	Underlying Deficiencies at Design Level
1. Failure of connectors to mate at the interface	• Different number of connectors at the interface • Different location, orientation, and layout of connectors with respect to the mechanical mounting interface • Different connector shell mechanical types (locking mechanism, etc.) • Different connector shell size • Different connector insert details - Number and size/type of pins - Arrangement of pins of each size/type - Pin connection mechanism details • Different convention regarding which side of interface has which sex of connector • Different connector materials (electrolytic compatibility, etc.) • Different connector shielding and grounding provisions
2. Lack of circuit continuity (or proper circuit termination) at the interface	• Different number and definition of circuits at the interface • Different allocation of circuits to various connectors (in a multi-connector interface) • Different allocation of circuits to connector pins (or other interfaces such as for fiber-optics circuits) within a given connector • Different termination of circuits that do not pass across the interface
3. Circuit incompatibility on the two sides of the interface	• Different impedance and/or transfer function characteristics of the various circuits • Different circuit bandwidths on two sides of the interface • Different circuit noise immunity on two sides of the interface • Different circuit current capability on two sides of the interface • Different circuit fault protection provisions on two sides of the interface
4. Waveform incompatibility on a given circuit	• Different maximum amplitude on two sides of the interface • Different basic or clock frequency on two sides of the interface • Different waveshape on two sides of the interface • Different signal stability on two sides of the interface • Different signal spectral distribution on two sides of the interface
5. Waveform incompatibility between two or more given circuits	• Different phase relationships between given circuits on two sides of interface • Different polarity relationships between given circuits on two sides of interface
6. Incompatibility of network architectures	• Hierarchy of buses different on two sides of interface • Location of intelligent terminals/bus controllers different on two sides of interface • Distribution of intelligence to subsystems different on two sides of interface

The interface system described in Table 2 may be standardized at different levels, i.e., for a given aircraft-store pair, the boundary between the standardized portion of the interface and the unique portion of the interface may be drawn at different levels. For an interoperable interface, all pairs using the interface design will have the same degree of standardization; however, the extent of the interface that must be designed uniquely may be different for each individual pair. The overall impact of the interface specification on the aircraft-store systems, therefore, depends on both the standardized portion and the individual custom portions.

From the lowest level to the topmost level, each succeeding level of operability builds upon the previous level to provide an increasing degree of standardization. The complete set provides complete electrical operability between aircraft and stores.

Clearly, standardization at increasing levels will provide greater degrees of operability and interoperability. However, the higher levels of standardization may impose increased system costs or undesirable system constraints. Therefore, it is necessary to evaluate succeeding levels of standardization to determine the benefits and identify associated costs and risks.

Table 2

OPERABILITY LEVELS CONCEPT

Levels of Operability	Standardization Alternatives
• Information interpretation management - Information interpretation (26) - Information sequencing (25) - Resource management (24) - Network management (23) - Information synchronization (22)	X
• Information content - Data precision/resolution/ scaling (21) - Data encoding (20) - Error management (19)	IX
• Information transport management - Standardized messages (18) - Information formatting (17) - Flow control (16) - Fault detection and correction procedures (15)	VIII
• Message management - Messaging structure (14) - Error detection, resynchronization, error correction procedures (13)	VII
• Multiplexing aspects - Data definitions/framing features (12) - Network control procedures (11) - Timing and synchronization features (10) - Addressing features (9) - Multiplexing scheme (8)	VI
• Assignment of signals to circuits (7)	V
Network topological features (6)	IV
• Signal features - On a given circuit (5) - Between two or more circuits (4)	III
• Transmission medium - Circuit physical architecture features (3) - Circuit electrical features (2)	II
• Connector mechanical features (1)	I

SMS ARCHITECTURES CONCEPTS

The two ASMS contractors initially responded to the contract specifications and requirements with proposed architectural configurations which indicate a direction for integration with other avionics systems.

Multiple Buses and Distributed Processing

Digital data bus architectures can be evaluated and selected by defining and developing the following parameters:

Information transfer redundancy	Efficiency (quality)
Information latency	Overhead (burden)
Throughput (Bus capacity)	

Because system data latency is proportional to the number of interconnected buses and the "inter bus" data transfer rates, the bus architecture becomes a key area for careful evaluation. The two selected contractors for the Navy and Air Force both proposed preferred architectures as proposal baseline concepts. Both of these, Figures 7 and 8 indicate multiple buses are desired for several reasons. A key reason is the flexibility and redundancy in distributing the digital processing made possible by these configurations. However, the tiering or layering of MIL-STD-1760 standardized interfaces made mandatory by multiple store carriers and future weapon configurations drives toward multiple buses with standardized characteristics. Experiments will be necessary to verify the effects on key system parameters.

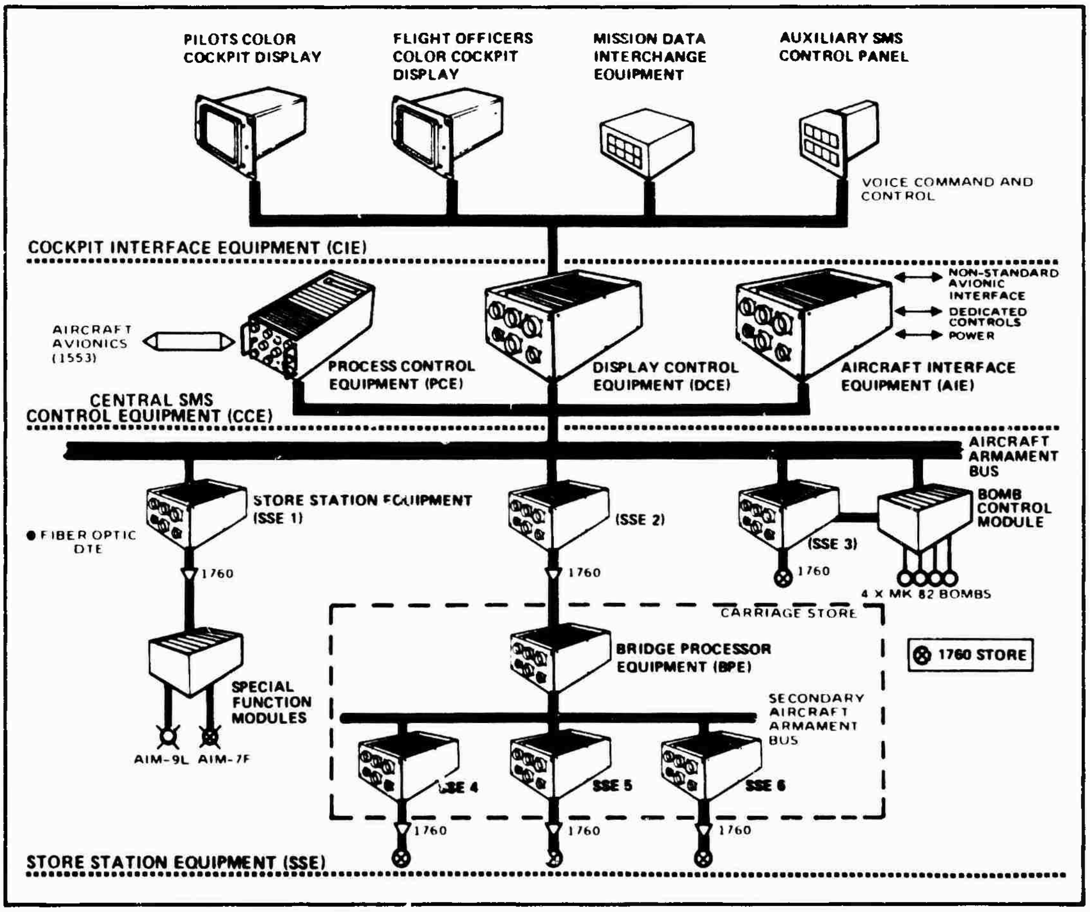


Figure 7. Contractor A baseline SMS configuration architecture

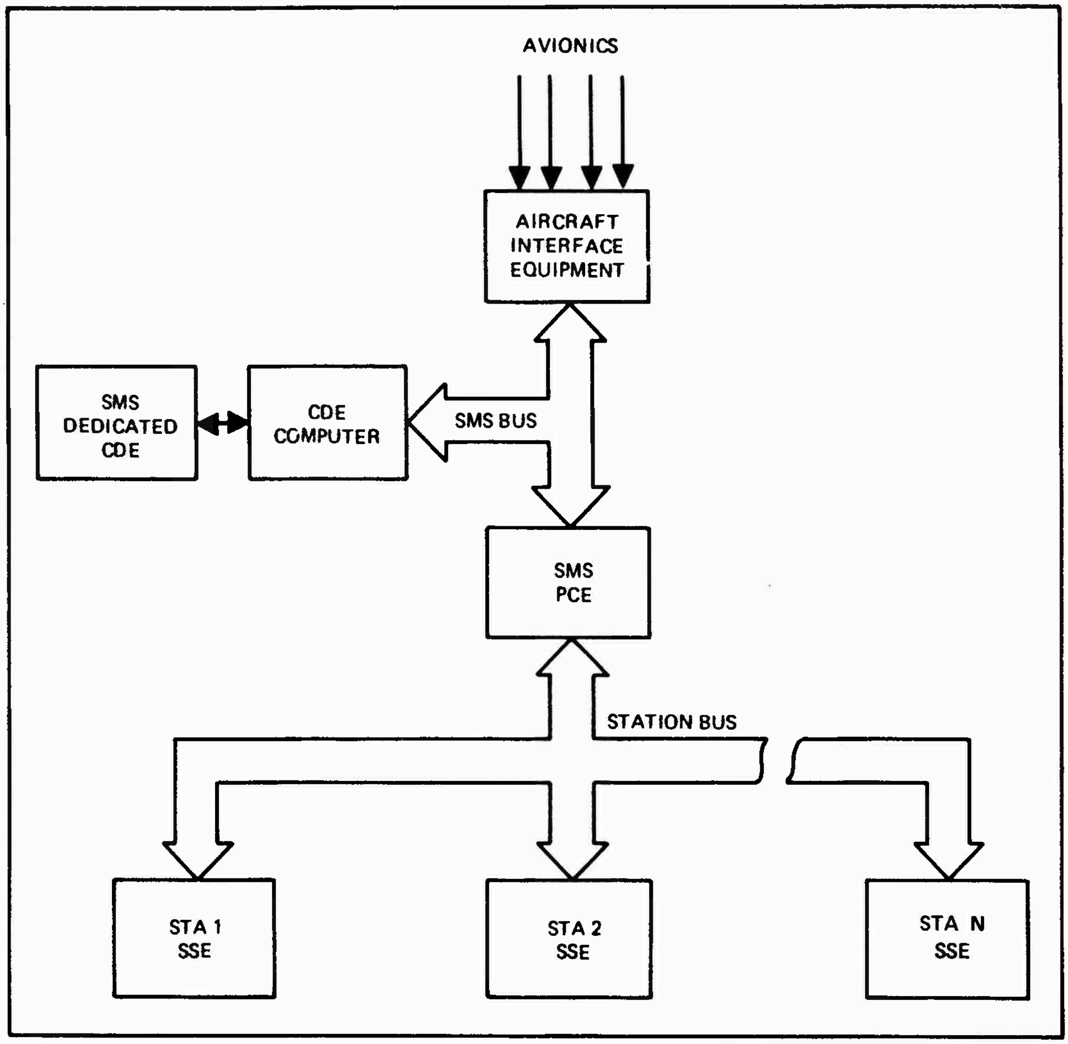


Figure 8. Contractor B baseline SMS configuration architecture

Total Aircraft Data Network

Many different digital data communication "buses" which do not conform to MIL-STD-1553 are used on current aircraft systems. The diverse system architectures and interface requirements of existing aircraft make necessary the provision for avionics integration modules or units, individually designed to adapt the SMS to the aircraft in which it is used. The expected functions required are easily discernable; they involve the common methods of data and control transmittal. The functional sizing, A-to-D converter size, number of DC outputs, word size of non-MIL-STD-1553 buses, etc., can only be derived from the specific application. Typically, the numerous, dissimilar I/O elements each have their own timing and response requirements.

In the use of the newer system designs, consolidation, sharing, and standardization of digital buses should yield large savings from reduced systems complexity. Further, if the whole data network of the aircraft could be controlled with standards to produce a common information transmission system into which technologically growing avionic subsystems could be exchanged, updated and replaced easily, all aspects of the aircraft mission readiness, and life cycle could be improved. Again, this is not a unique concept implied by SMS efforts alone and has been gaining favor in various design groups around the country. As the architectural and system trade studies progress, this total aircraft data network gathers more and more interest. Figure 9 shows how armament controls data bus requirements could serve as the initial source for integration and consolidation. The pilot interfacing with the aircraft weapon system during a mission, typically passes inward from mission and Fleet interfaces and actions, through aircraft systems and weapons systems interactions to the final weapon release. Common functions in armament controls leading back to common functions in weapon system support—leading to common interfaces with other aircraft and mission support functions—making possible important system integrations and simplifications.

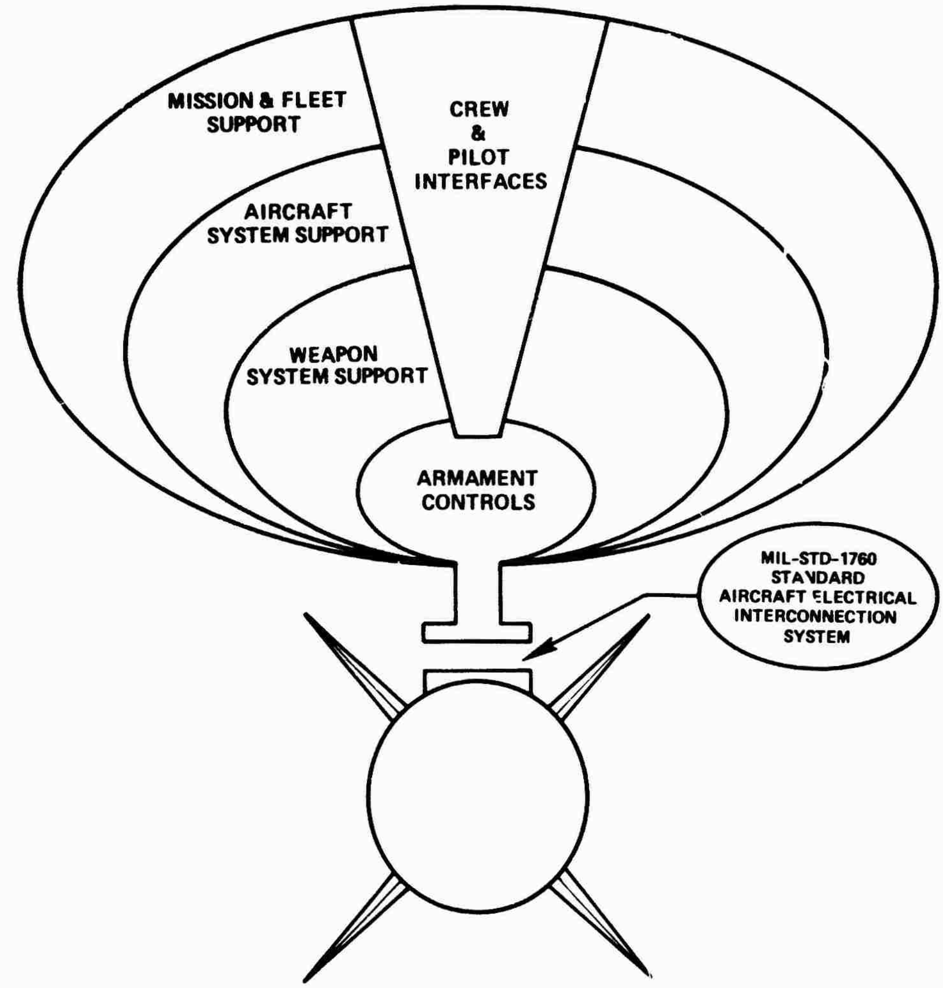


Figure 9. Pilot interactions with avionics progress from top to bottom

Fiber Optic Application

The airborne fiber optic studies over the last several years coupled with the success of the communications industry in applying this technology has peaked the interest of system designers. The advantages are numerous and the current disadvantages almost as numerous. The AAAS intent through '79, '80 and '81 was to attempt the implementation of an advanced fiber optic SMS. Fund shortages and industry evaluations of technical risks caused the objective to be dropped in favor of wire-based. However, several proposals of fiber optic SMS configurations were received and evaluated in the process of awarding the current contracts. As components mature airborne fiber optics could become a reality. Figure 10 shows the impact of fiber optics on the specific architecture shown in Figure 8. The SMS configuration will include five identical digital fiber optic data buses: (a) avionics bus, (b) stores management bus, (c) left-wing store stations bus, (d) fuselage store station bus, and (e) right-wing store stations bus. Each bus employs a six-terminal reflective star coupler and single-fiber cable pigtails (without connectors).

The resolution of two critical issues arising from prior fiber optics development of airborne applications was completed and may be of interest. An analog decoder technique was successfully used to eliminate the signaling errors typically encountered in fiber optic data bus systems which employ 2-State Manchester Coding. An improved LED driver technique was developed which provides increased output power at wide bandwidth. Both techniques can now be exploited in airborne fiber optic system design effort.

Software Development Tools

A major objective of the AAAS effort is to develop systems hardware and software which provides rapid, very low cost, minimum modification, and capability growth. The addition of new weapons to older aircraft weapon suites represents this need. One of the contractors selected for the ASMS development will implement a concept which simplifies the generation of store control procedures, store control tables and specific aircraft application configurations. The system generation portion of this new tool is diagramed in Figure 11. Development of this tool provides adaptability to reconfigure software among various processors while minimizing any software programming. It utilizes table driven software to facilitate control sequence changes and simplifies addition of new stores to the SMS.

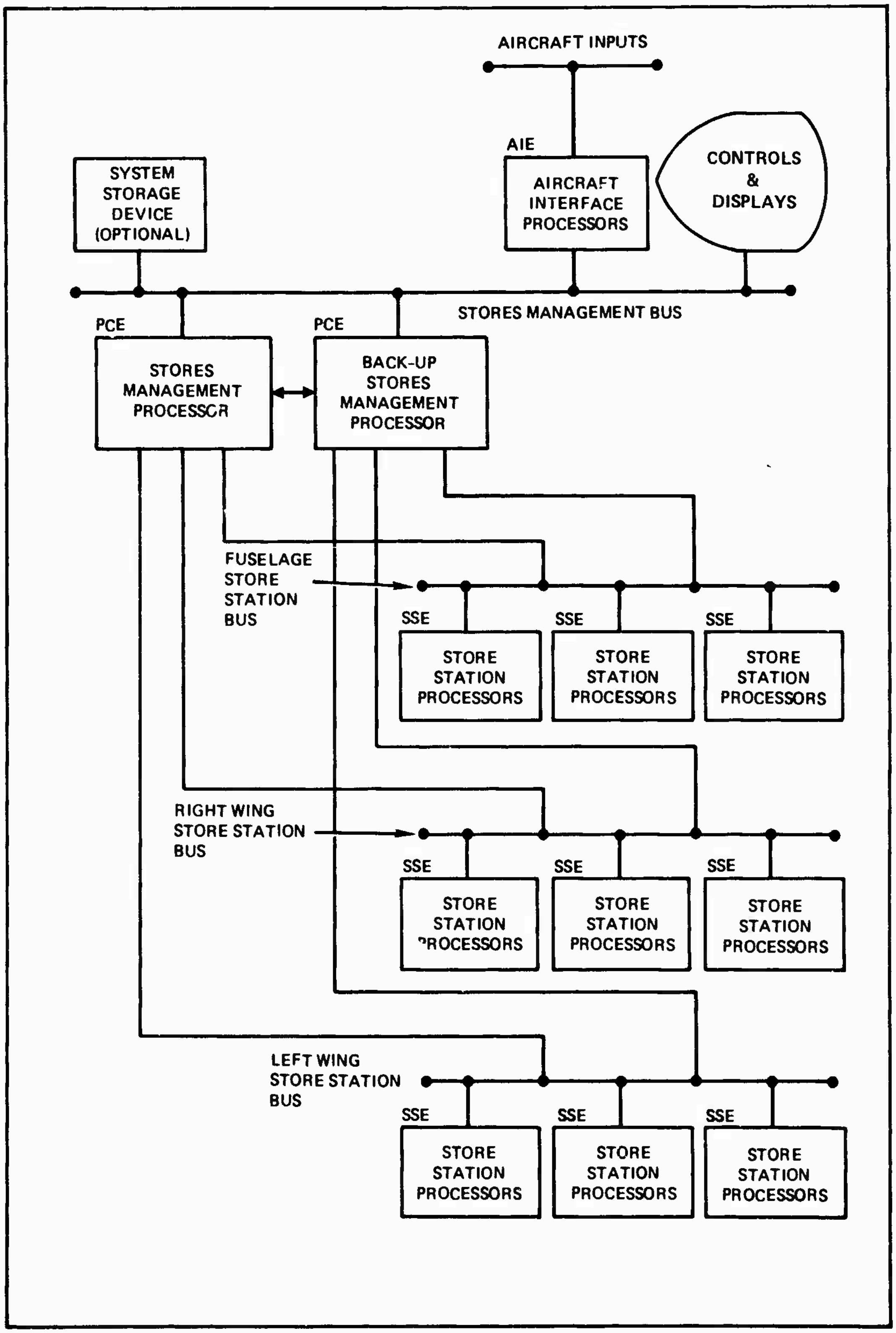


Figure 10. Contractor B SMS architecture with fiber optics data buses

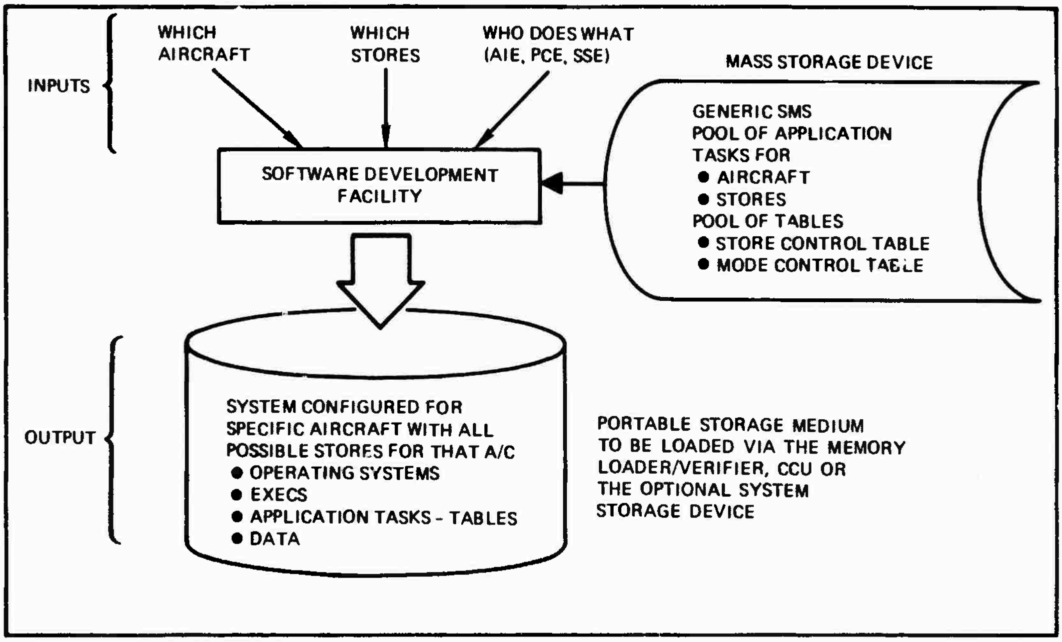


Figure 11. Store data software system generation

Use of the system by the Navy and eventually the AAII would enhance the concept of a DoD wide weapon aircraft system data base by providing a guide for data formatting and management.

SMS SUBSYSTEM STANDARDS

A concept which may be utilized for the evaluation of standardization in other avionics systems has been developed under AAAS direction effort. A set of criteria were developed to rank subsystems modules or components (levels) for the application to standardization by any of several approaches.

Standardization is the process requiring conception, formulation, dissemination, enforcement, and revision of standards. Six types of standardization are frequently used in Government and industry. These standardization types are summarized below.

Horizontal
Vertical
Area
Functional
Logistical
Cooperative

Horizontal standardization, also termed general, commodity, or intersystem standardization, refers to standardization of items (subsystems, modules or components) used between or within systems. An item used in more than one system (e.g., utilizing an AN/AYK-14 in more than one aircraft series) may also be used by more than one military service and often satisfies multiple missions. Example is AN/AYK-14.

Vertical standardization, also known as specific, project, product, or intrasystem standardization, refers to standardization of a project or product from design to operation. Vertical standardization includes an item used in all configurations of a single system. Example is AN/AYQ-9 in all F-18 aircraft.

Area standardization is standardization of items by geographic or mission area rather than between or within systems. When there is more than one supplier or application of a given item, these items are typically similar but not identical. Therefore, to meet area or mission needs, items are standardized within a mission or geographic area, whereas similar but not identical items are used between areas or missions. Example of area standardization is to use functionally similar items for strike and surveillance aircraft, but identically standardized items in a specific mission area (e.g., strike aircraft).

Functional standardization, also known as form, fit and function (F^3) standardization, is primarily concerned with the standardization of electrical, mechanical, logistical, and environmental interfaces. Items built to F^3 standards may differ significantly internally, but always have identical size, shape, and function. Commercial airlines have employed this form of standardization for many years in the specification of avionics. This form of standardization is also used to establish joint service standards (MIL-STD-1760) and NATO standards (STANAG 3837AA).

Logistical standardization is the specification of every aspect of an item, including the detailing of its parts, processes, and configuration. Examples of logistical standardization are military-qualified electronic components managed by the Defense Electronics Supply Center. Each logistically standardized item is identical in every respect to other standardized items.

Cooperative standardization is the development of design standards (examples include threads, fitting sizes, and materials) by all users, both industry and DoD.

Standardization studies conducted over the past few years have recognized that not all items make good standardization candidates, for technical, operational, or economic reasons. Presently there are no universally accepted, quantitative measures for determining the attractiveness of a particular subsystem for standardization. However, general guidelines for making such evaluations have been developed in recent AAAS studies. Four general selection criteria were developed and applied that were widely accepted by the R&D community. These criteria are briefly as follows:

Technological - The technology must be mature.

Architectural - The subsystem must perform identifiable, discrete, and separable functions.

Applicability - The system specification must be broadly applicable to weapon system requirements.

Economic - A sufficient market must exist for new systems within the period under consideration.

It is realized that these criteria are not a comprehensive set of considerations for selecting standardization candidates; however, a review of SMS subsystems against these factors encourages a disciplined examination, providing useful insight into the issues that must be reconciled.

Table 3 categorizes these criteria for ranking the seven AAAS SMS subsystems for potential standardization. Table 4 shows the results of applying the criteria and rationale together with each subsystem candidate's raw score and ranking.

Table 3 STANDARDIZATION-RANKING CRITERIA FOR SMS SUBSYSTEMS

		Category	
Criteria	Least Attractive (1)	Moderately Attractive (2)	Most Attractive (3)
Technological	Performance requirements change frequently; state-of-the-art pacing equipments.	Functionally similar equipments exist in the inventory. Improvements (primarily packaging, reliability, etc.) are expected.	Previous standardization precedent exists. Equipment currently exhibits high MTBF using proven technology and mature designs.
Architectural	High degree of interconnectivity with other avionics subsystems; moderate or higher degree of software implementation within subsystem.	Low degree of interconnectivity with other subsystems; moderate or higher degree of software implementation within subsystem.	Low degree of interconnectivity with other subsystems; very low software implementation.
Applicability	Used only in aircraft with similar performance characteristics or that operate in identical threat environments.	Used across multiple-aircraft types and in other military services.	Multiple mission and multiple aircraft or commercial usage.
Economic	Few suppliers and low annual demand rate — limited opportunity for competition.	Some suppliers and medium annual demand rate — some opportunity for competition.	Many suppliers and high annual demand rate — unlimited opportunity competition.

Table 4 STANDARDIZATION SCORES AND RANKING FOR SMS SUBSYSTEMS

SMS Subsystem	Standardization Criteria Application and Ranking					
	Technological	Architectural	Applicability	Economic	Raw Score	Rank
Control and Display Equip.	2	1	1	2	6	7th
Process Control Equip.	3	2	2	3	10	3rd
Store Station Equip.	2	2	1	2	7	6th
Aircraft Interface Equip.	2	1	2	2	7	5th
Data Transfer Equip.	3	3	3	3	12	1st
Software	3	3	2	3	11	2nd
Briefing Entry Device	3	2	2	3	10	4th
Note: 3 = Most Attractive, 2 = Moderately Attractive, 1 = Least Attractive						

A discussion of the rationale for ranking the top four subsystems follows.

Data Transfer Equipment (DTE)

Data Transfer Equipment is considered most attractive for standardization based upon all criteria. DTE has standardization precedents (e.g., the MIL-STD-1553 multiplex data bus), highly standardized means for interconnectivity with other systems, and multiple mission/aircraft applications. Many companies supply DTE components, thus sustaining an unlimited opportunity for competition.

As a result of the above analysis, DTE was given the highest raw score of all SMS subsystems (12/12) and hence is regarded as the most attractive for standardization. All standardization approaches except functional are recommended, and standardization is achievable at all levels.

Software (SW)

The software subsystem is considered most attractive for standardization in all categories except applicability. Previous standardization precedent exists (e.g., standard HOL and MIL-STD-1679) and SW interfaces can be strictly defined through interface design specifications. Further, there are several potential suppliers of the SW subsystem, thus providing an unlimited opportunity for competition.

The SW subsystem as judged moderately attractive based on the applicability criterion, since only portions of the SMS subsystem (e.g., executive programs) may be used across multiple-aircraft types and potentially in other military services. It is expected that selected modules of SMS subsystems (e.g., application programs) will be needed to accommodate different aircraft configurations and store suites.

The SW subsystem accumulated a raw score of 11/12 and was judged the second most attractive of the SMS subsystems candidates for standardization. Standardization to the module level is considered feasible.

Process Control Equipment (PCE)

Process Control Equipment is rated most attractive for standardization on the basis of technological and economic criteria (see Tables 3 and 4). PCE scores well in these areas since there is precedent for its standardization (AN/AYK-14, AN/AWG-9, etc.), and such equipment utilizes proven technology and mature designs. Further, the many potential suppliers of PCE offer an excellent opportunity for competition.

PCE is considered moderately attractive for standardization based upon architectural and applicability criteria. The reasons are that PCE interfaces with other subsystems (although this interface is increasingly being simplified through the use of standard digital multiplexes busses), and typically differs in capability and mission supported.

The PCE reflects a total raw score of 10/12 (see Table 4) and ranks third overall as an AAAS subsystem candidate for standardization. PCE is considered feasible for standardization at all assembly levels and to all standardization approaches. However, functional standardization is not recommended since the logistical approach is achievable and has been demonstrated to the component level.

Briefing Entry Device (BED)

The Briefing Entry Device was judged most attractive based upon the technological and economic criteria, and moderately attractive for the architectural and applicability criteria. From a technological viewpoint, standardization precedent exists (e.g., Data Transfer System) and equipment making up the Briefing Entry Device incorporate proven technology and mature designs.

Further, there are many current suppliers of such subsystems, thus offering an unlimited opportunity for competition.

The moderately attractive ratings in the architectural and applicability areas were assigned, respectively, because the device (1) has a degree of interconnectivity with other subsystems, and (2) may not be adaptable across multiple aircraft types in a single configuration.

By applying the above criteria, the Briefing Entry Device attained a raw score of 10/12, suggesting that it is a favorable candidate for standardization. All standardization approaches except functional are recommended. Standardization to the module level is considered feasible, while complete component standardization may be difficult due to a requirement to adapt to different aircraft types and missions.

CONCLUSIONS

The series of concepts discussed above were selected for potential application or interest by other avionics developments. Due to a shortage of advanced development funds the application of these and other concepts may not be carried further by the AAAS program.

DISCUSSION

R.Davies, Ca

With regard to MIL-STD-1760 – has any consideration been given at Naval Weapons Center (or elsewhere) to extending the interface standard beyond the physical connection between the aircraft and the store (weapon missiles, etc.), for example, with a data link or wire-guided missile or a back link from an E-O weapon etc?

Author's Reply

To my knowledge no one is looking at this or for that matter pushing it. My instinct would be to let it mature a bit before standardization.

M.Burford, UK

In your presentation, you have identified that where there is a software interface, the standardization of the stores management system is "unattractive". This appears to be in direct contrast, in respect to standardization, to previous speakers. Could you please outline the thoughts which have led to this conclusion?

Author's Reply

Somehow we did not communicate well. The section in my paper on SMS subsystem standardization states very clearly that the software as an SMS subsystem is a most attractive candidate. I believe this to be in agreement with most other speakers.

K.F.Boecking, Ge

You presented two different architectures for a SMS. In system "A" the display/control system corresponds to the SMS via the avionics-bus. In system "B", the SMS-Bus has its own D/C-system at the SMS-Bus. Could you explain the reason for a separate D/C-system in the "B"-SMS?

Author's Reply

The separate controls/displays functional block on SMS system "B" is for the safety required separate discrete controls which cannot be integrated into multi-function controls through the avionics bus. Actually, all proposals received were identified in this characteristic including SMS "A". A look at the SMS system "A" figure in the paper will confirm this.

L.Wildharer, Ca

Are you considering standardization or adoption to commercial digital bus system, that is the use of ARINC Bus 429 for interphasing between standard commercial avionics systems (digital) and aircraft weapon systems? This refers to Table 3 Applicability – Most attractive (3).

Author's Reply

Yes, under study with regard to input-output parameters for standardization.

G.R.England, US

(1) Future for SMS implementations where real time data is required will likely be a network rather than a hierarchal bus system. A switched network would be applicable to any type of real time requirement.

(2) Master arm type data is generally made available to the rest of the avionics by means of a discrete to the Fire Control Computer. By this means, the data can be put on the bus yet retain necessary isolation for safety.

Author's Reply

(1) Yes, thank you, an excellent point.

(2) Again, thank you, for help in answering the question from Germany.

LIAISONS AVION-CHARGES EXTERNES

PAR

C. CONNAN

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1 - RESUME

L'évolution en complexité des charges externes dites simples (bombes), le nombre de plus en plus important des paramètres demandés par les charges plus complexes (missiles et surtout nacelles) rend indispensable la numérisation d'un maximum de matériels.

Ceci conduit à standardiser le procédé de liaison numérique (type de liaison et gestion). Alors les seules autres informations restant à interfacer sont des informations de sécurité et des informations à large bande passante, elles peuvent être commutées en fonction du chargement de l'avion à condition d'avoir prévu un système d'identification et d'adressage des charges. Par sécurité les informations autorisant le tir des armes ne sont pas entièrement numérisées et sont ségréguées électriquement des autres signaux.

Le projet de stanag 3837 propose également une standardisation des interfaces électriques des charges externes afin de répondre aux mêmes besoins que ceux de notre étude. Cependant il impose le type de liaison numérique de l'avion, ce qui n'est pas nécessaire pour l'intéropérabilité ; toutes les sécurités sont traitées par doublage de la liaison numérique sans aucune liaison spéciale.

Dans une phase intermédiaire il est possible d'aboutir progressivement à l'architecture que nous exposons ici dans des avions existants, en cours de développement ou à développer : dans l'ordre nous trouvons d'abord liaison numérique, puis aiguillage des informations analogiques, puis numérisation des ordres de tir précis.

2 - INTRODUCTION

Cette publication représente le point de vue des Avions Marcel Dassault - Bréguet Aviation vis à vis des architectures de liaisons avec les charges externes.

Le but de l'étude présentée est de standardiser au maximum les interfaces électriques entre les avions et les charges externes afin de minimiser :

- les études d'adaptation — pour l'adaptation de chaque type
- les développements de matériels spécifiques — de charge externe à chaque type d'avion
- les modifications des câblages et d'installation, lors de l'adaptation d'une nouvelle charge externe à un avion. Le but n'est pas l'interopérabilité des avions, sans aucune modification de logiciel ou des adaptations au niveau des points d'emport, mais essentiellement ne pas modifier le matériel interne à l'avion, et agir uniquement au niveau du logiciel.

3 - EVOLUTION DES CHARGES EXTERNES

Une classification possible des charges externes en fonction de leurs évolutions propres actuelles est la suivante :

- les bombes dont les installations mécaniques sont standardisées (tout au moins pour les systèmes d'accrochage et les éjections) (cf § 3.1).
- les missiles qui sont toujours installés sur des lanceurs spécifiques (cf § 3.2).

- les nacelles soit qui possèdent des adaptateurs mécaniques intégrés, soit qui se montent comme des bombes (cf § 3.3).

Cette classification ne prend pas en compte les interfaces spécifiques au tir mais uniquement les liaisons "fonctionnelles".

3.1 - Bombes

Les bombes ont évolué en partant de systèmes extrêmement simples ne nécessitant aucune liaison avec l'avion vers des systèmes de plus en plus sophistiqués nécessitant de plus en plus de liaisons avec l'avion.

Très grossièrement l'évolution des interfaces avion-bombe permettant de transmettre des informations fonctionnelles est :

- aucune liaison entre l'avion et l'arme
- les informations nécessaires à l'arme sont mécaniquement (ou parfois électriquement) affichés sur l'arme au sol avant le départ en mission. Ceci nécessite d'introduire les mêmes informations dans le système avion par un autre moyen. D'où des risques de contradiction et d'erreur non négligeables.
- les informations sont en nombre très réduits (2 cas possibles seulement) et sont transmis par les câbles mécaniques commandant les sécurités largables.
- afin de minimiser les consignes aux pilotes et augmenter les performances des systèmes les informations sont transmises électriquement de l'avion à la bombe. Compte-tenu des technologies disponibles, une liaison numérique est choisie (ce qui permet également d'avoir une prise de plus faible dimension). Mais, dans l'espoir de minimiser le coût de l'arme (qui est consommable), la liaison est la plus simple possible et généralement spécifique
- les kits de propulsion sont envisagés sur certains types de bombes

3.2 - Missiles

L'évolution des interfaces dans le cas des missiles est :

- liaison uniquement pour le tir (amorçage des piles, allumage du propulseur, etc...)
- liaisons analogiques fonctionnelles de plus en plus nombreuses
- liaisons numériques + liaisons discrètes d'identification + liaisons de sécurité + liaisons à large bande passante (blankings et synchronisations avec les contre-mesures et le radar en particulier, liaisons vidéo). La liaison numérique est généralement choisie en fonction de la complexité nécessaire (nombre d'informations à transmettre, rapidité de transmission nécessaire, précision de la détection des informations)
- des systèmes d'extraction permettant de protéger les prises de la flamme des propulseurs sont de plus en plus employés.

3.3 - Nacelles

L'évolution des nacelles est très proche de celle des missiles si ce n'est qu'il n'y a pas de liaison pour le tir. Cependant elles peuvent nécessiter des alimentations en énergie électrique relativement importantes.

4 - DEFINITION DU BESOIN

4.1 - Standardisation

Le nombre d'informations différentes à transmettre entre les avions et les nombreuses charges externes qu'ils doivent emporter (compte-tenu de leur polyvalence de plus en plus grande) conduit :

- soit à multiplier les boîtes d'interfaces, (bien que les fonctions réalisées par ces différentes boîtes aient de nombreux points communs), les torons de câblages et les commutations de câblage à l'intérieur de l'avion. C'est la solution qui existe dans les avions actuellement en service ;
- soit à standardiser les liaisons entre l'avion et les charges externes ; ce qui implique :

  . de numériser au maximum les informations et les transmettre par une liaison numérique standardisée.
  . que les liaisons non numérisables seront aiguillées dans l'avion par des équipements spécialisés.

4.2 - Liaison numérique

L'avantaga assantiel de la liaison numérique est de pouvoir changer les informations qui sont transmises sans avoir à modifier le matérial avion.

La liaison numérique doit être utilisée au maximum et descendre le plus en aval possible dans les charges externes. En particulier, tous les problèmes de séquencement et da tir doivent être traités par cette liaison. Les gros avantagas de la liaison numérique conduisent à un gain de volume et de masse et un gain dans la disponibilité globale du système. Ceci implique en particulier que le gérant de la liaison numérique soit capable de reconnaître chaque équipement relié à la liaison. Pour ce qui concerne les charges externes, ces équipements sont :

- das interfaces dans les pylones
- des interfaces dans les adaptateurs spécifiques.
- les charges externes alles mêmes qui peuvent comporter plusieurs équipements.

Tout ceci implique la standardisation :

- des adressages des charges externes sur la ligne numérique. Au niveau de chaque point d'emport, l'avion doit donc fournir une adresse. La loi d'adressage au niveau de chaque point ast également standardisée avec une capacité d'adressaga suffisante.
- chaque équipement doit êtra capable de s'identifier ; un code standard d'identification doit donc être établi. Un moyan annexa est nécassaire pour les charges ne possédant pas de liaison électrique (affichaga manuel - détrompagas mécaniques).

Il est bien évident que s'il doit rester des liaisons spécifiques au niveau des emports, il en résultera des complications considérables des problèmas de gastion des amports qui peuvent conduire jusqu'à nécessiter des gérants locaux de liaisons spécifiques au niveau de chacun des points d'emport.

Par ailleurs, las liaisons spécifiques impliquent des moyans de maintenanca spécialisés qui ne sont pas nécessaires dans le cas d'une liaison standardiséa. C'est pourquoi nous essayons d'éliminer cas liaisons spécifiques dans l'avion, l'adaptation éventuella étant dans la pylone ou l'adaptateur, ca qui est réalisable (voir § 5.4.3) et permat de répondre au basoin d'interopérabilité.

4.3 - Liaisons fonctionnallas restantas

Les liaisons fonctionnelles restantes sont calles qui ne sont pas numérisables sur une liaison numérique série :

- liaisons à large bande passante de type :
  . blanking entre équipements possédant des antennes d'émission ou de réception.
  . synchronisation d'équipements (synchro radar - synchro vidéo - GPS - etc...)
  . signaux vidéo d'imagerie (analogiques ou numériques) les bandes passantes de ces signaux vidéo correspondant :
    * aux vidéos actuelles (525 et 625 lignes)
    * aux vidéos en cours de développement, en particulier pour les besoins de reconnaissance (875 lignes).

- Liaisons de sécurité de type :
  . coupure d'alimentation d'une charge externe ou d'une partie de charge externe. Ce type de liaison existe surtout pour des nacelles qui ne sont pas des matériels consommables et qu'il est donc parfois nécessaire de pouvoir protéger par une action manuelle,
  . autorisations de tir. La liaison numérique permet d'obtenir des instants de tir précis avec un minimum de câblage et de matériel dans l'avion mais elle ne garantit pas une probabilité de tir intempestif ou de non tir suffisamment faible pour être utilisée seule. C'est pourquoi il reste indispensable de n'alimenter les circuits de tir que pendant des temps courts (sécurité armement levée et poussoir de tir enfoncé en particulier).

Bien entendu, compte tenu de la progression rapide des technologies, ces liaisons de sécurités pourront être petit à petit partiellement ou totalement supprimées et remplacées par des redondances au niveau des interfaces et des gestionnaires de la liaison numérique. L'état actuel des technologies ne permet cependant pas de les supprimer immédiatement (bien que les liaisons numériques aient des fiabilité et disponibilité de fonctionnement globalement meilleures que celles des liaisons analogiques) :

- les probabilités recherchées ne sont pas atteintes ou sont difficiles à démontrer
- les redondances impliquent également des redondances des câblages numériques qui sont très pénalisantes en volume parce que ces liaisons doivent être protégées.
- les coûts et volumes dans les technologies actuelles sont trop importants.

4.4 - Alimentations

Les alimentations doivent être distribuées vers chacun des points d'emport. Les évolutions des circuits d'alimentation pour les avions futurs ne sont actuellement pas parfaitement établies ; l'hypothèse faite est donc de fournir :

- du 200V 400 Hz
- du 28 V continu

à chacun des points d'emport où une charge est installée (une nacelle ou un missile ou un lance missile, etc...).

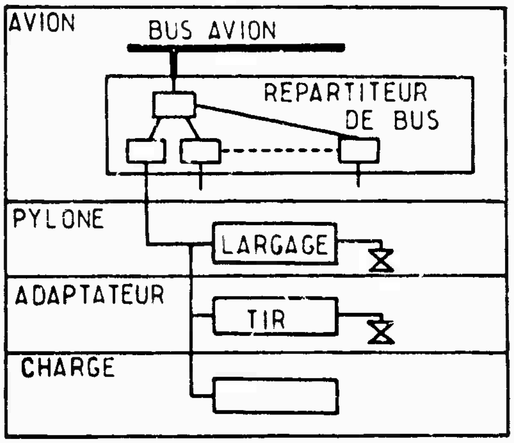
Les technologies actuelles conduisent à diminuer les consommations des équipements. Cependant de gros consommateurs apparaissent de plus en plus nombreux, en particulier des émetteurs radio électriques (de contre-mesure par exemple); il est donc nécessaire de fournir les meilleures puissances possibles.

5 - ARCHITECTURE PROPOSEE

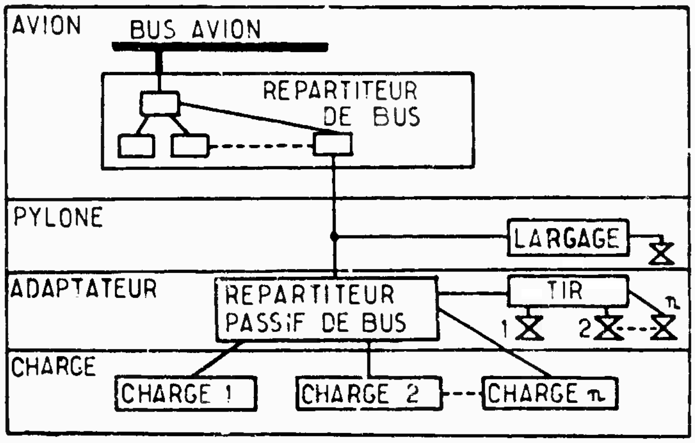
Pour répondre aux différents besoins exposés au chapitre précédent, une architecture de système de gestion des points d'emport peut être proposée. La synoptique de principe est établi en annexe.

Elle est bâtie autour d'un système de gestion numérique.

5.1 - Liaison numérique



point d'emport mono charge



point d'emport multicharge

La distribution de la liaison numérique vers les points d'emport se fait en étoile :

- ceci permet de découpler électriquement le bus avion des bus allant vers les points d'emport et chaque point d'emport l'un par rapport à l'autre. En particulier il n'y a pas de possibilité de perturbations mutuelles au moment du tir d'une arme ou après son tir.
- la coupure de la liaison vers l'un des points d'emport ne conduit pas à la perte des liaisons vers tous les autres points d'emport.

5.1.1 - Fonction répartition des bus dans l'avion vers les points d'emport

Cette fonction peut être réalisée de plusieurs manières suivant le nombre d'abonnés à la ligne numériqua :

- si la nombre d'abonnés au bus avion (équipements internes à l'avion + équipements aux points d'emport) est inférieur au nombre maximum d'abonnés possibles par bus : c'est un simple répéteur de bus (simple remise en forme des signaux électriques).
- si la nombre d'abonnés au bus avion est supérieur au nombre d'abonnés par bus : c'est un coupleur de sous bus (avec adressage complémentaire de sous bus),
- si le nombre d'abonnés installés aux points d'emport devient très grand c'est un ensemble de coupleurs de sous bus.

Ce principe permet d'avoir, pour une installation avion figée, la possibilité de faire évoluer le système vers un plus grand nombre d'abonnés par simple remplacement de l'équipement faisant la répartition de bus vers les points d'emport.

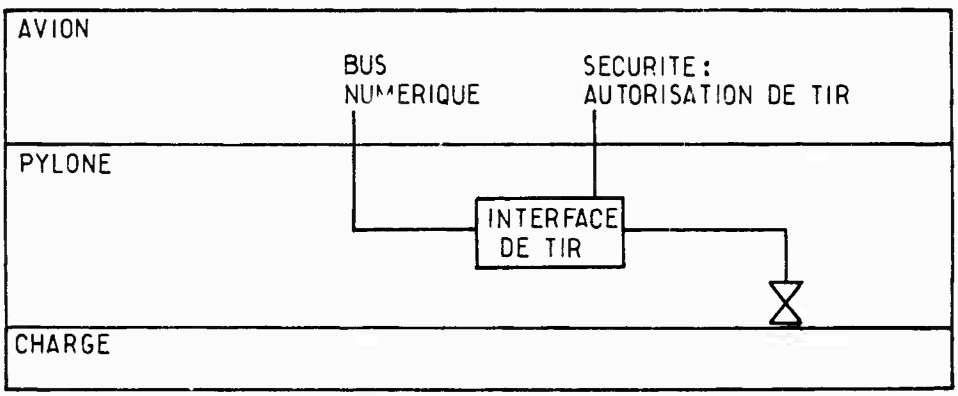
5.1.2 - Répartition de bus au niveau de chaque point d'emport

Afin de minimiser les volumes et les coûts dans les équipements de charges externes, la répartition de bus au niveau des points d'emport se fait :

- par répartiteur passif (transformateur + résistance) tant que le nombre d'abonnés au bus à un point d'emport donné n'est pas supérieur au nombre maximum possible pour un bus,
- si toutefois ce nombre était dépassé pour un point d'emport donné (ce qui est très peu probable) il devient nécessaire d'installer des coupleurs de sous bus au niveau des points d'emport.

5.1.3 - Numérisation de la fonction tir

Afin de profiter au maximum des possibilités de la liaison numérique les paramètres permettant d'obtenir un instant de tir précis sont transmis sur la liaison numérique :



Afin de minimiser les risques de tir intempestif, les circuits de tir ne sont alimentés que lorsque toutes les sécurités sont lavées (train - sécurité générala armament - poussoir de tir - palettes aérodynamiques). Cette sécurité est réalisée de façon classique par matériel dans l'avion.

Les progrès technologiquas davraient permettre ultériaurement da suprimar cas liaisons de sécurité ; par axemple :

- redondance multiple du traitement logicial das différents inverseurs de sécurité dans l'avion avac votaur en sortie,
- redondance multipla das outils de liaison numérique (il n'ast pas nécessaire de redonder la câble lui-même),
- éventuellemant redondanca de l'interface de tir.

Cecl ne sera possibla qua lorsque ces fonctions pourront être réalisées dans des volumas raisonnables et à des coûts faibles ; ce qui n'est pas le cas à l'haure actuella.

L'interface de tir, située dans les pylones, transforme les signaux reçus sur le bus (précis sur l'échelle des temps) en signaux capables :

- de réaliser le séquencement du tir :

  . tir successif de plusieurs armes emportées sous le même pylone,
  . séquence pour une seule arme : activations de piles, suppression de verrou, mise à feu de propulseur, etc...

- de fournir une énergie suffisante aux différents systèmes pyrotechniques

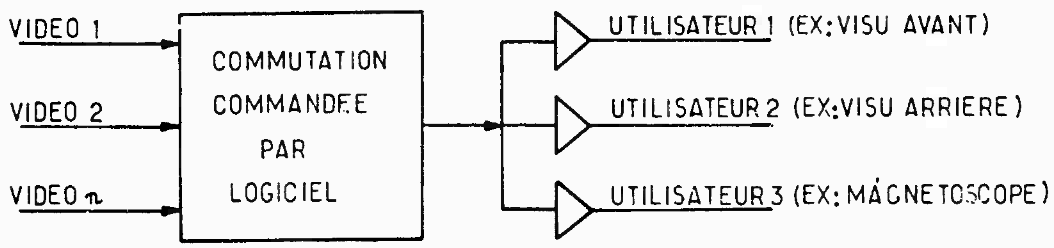
5.2 - Aiguillage des liaisons fonctionnelles

Pour une mission donnée (ou parfois pour une phase de mission donnée seulement) un signal analogique issu de l'avion n'est utilisé que sur un point d'emport à la fois. Il y a donc un aiguillage programmable de ces signaux réalisés dans un équipement installé dans l'avion :

- signaux de sécurité (hors largage et tir)
  ces signaux sont en fait issus d'inverseurs situés sur des postes de commande en cabine pilote. A chaque inverseur correspond un fil allant vers un point d'emport donné ; c'est le poste de commande qui est réalisé en fonction des points d'emport et non en fonction des types d'emport.
- signaux vidéo
  plusieurs générations successives de systèmes peuvent être envisagées :

  . la vidéo n'est utilisée que pour visualisation et enregistrement,

    * une seule vidéo est utilisée simultanément dans l'avion: une commutation simple (1 parmi N) suffit avec séparation des circuits de sortie :



    * deux vidéos sont utilisées simultanément dans l'avion : la commutation est plus complexe (2 parmi N). Ce cas se présente, par exemple, si l'on veut visualiser, soit des vidéos différentes aux différents membres de l'équipage, soit des vidéos différentes au pilote en monoplace.

  . la vidéo est également utilisée pour réaliser des traitements d'image dans l'avion : une commutation n parmi N est alors nécessaire.

- signaux de blanking
  le gérant de ce type de signaux est généralement l'équipement gérant des contremesures. A un instant donné, les signaux à aiguiller vers le gérant des contre-mesures sont issus :

  . des différentes nacelles de contremesures,
  . de l'arme qui est sur le point d'être tirée

- signaux de synchronisation radar
  un aiguillage simple depuis le radar vers le missile sur le point d'être tiré suffit dans ce cas.

Les autres signaux sont tous numérisables. Si des signaux de type phonie, par exemple, doivent être fournis à des nacelles de transmission, une commutation simple est suffisante.

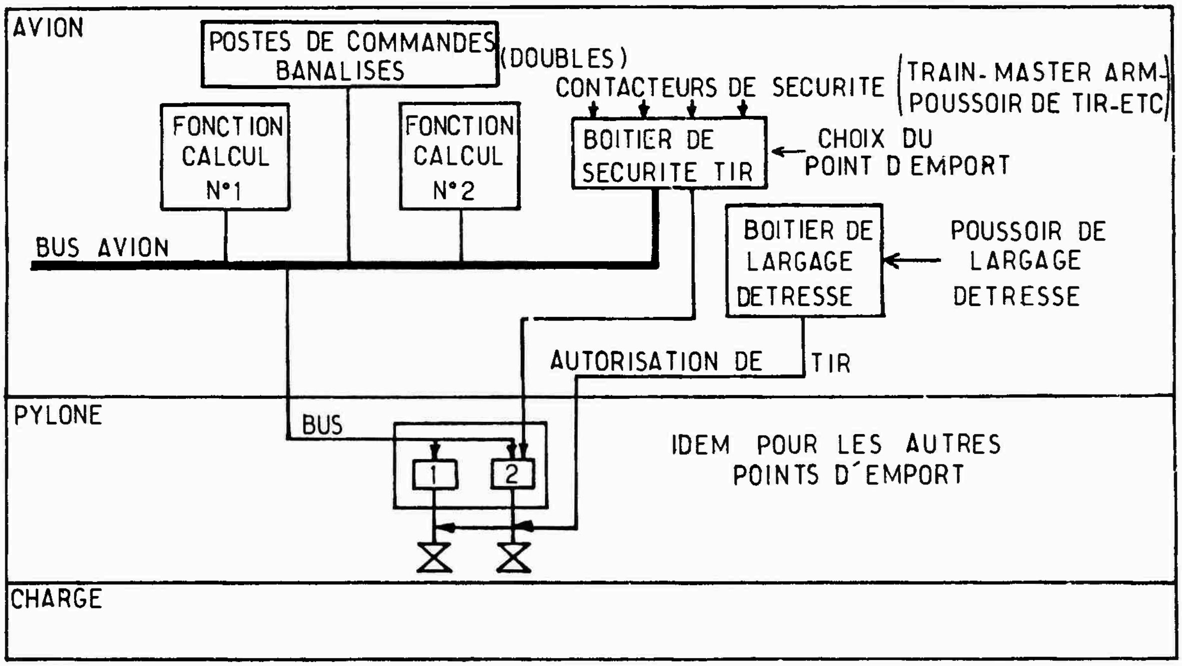
5.3 - Circuits de tir et de largage

Les circuits de tir et de largage peuvent être classés en :

- circuits de tir opérationnel
- circuits de détresse évoluée (largage combat - largage sélectif)
- circuits de détresse générale.

Les deux premiers types de circuits nécessitent des séquences complexes et variables en fonction des conditions de tir. Une gestion par calculateur est nécessaire ainsi que la transmission par liaison numérique. Le troisième type doit être disponible même après perte totale de l'alimentation alternative de l'avion et du système d'arme.

Afin de répondre a ces deux critères et de conserver une certaine redondance des circuits utilisant les calculateurs de gestion numérique l'architecture suivante des circuits de tir est proposée :



Le matériel est utilisé pour le tir opérationnel secours et pour les détresses intelligentes ; ceci afin de minimiser le matériel nécessaire et de profiter du maximum des possibilités des logiciels. Le largage détresse ne fait pas intervenir de logiciel et reste complètement indépendant du reste du système.

L'évolution de la technologie devrait permettre dans le futur de redonder certaines parties de circuits (avec comparaisons par voteurs par exemple) dans des volumes très faibles et autoriser la suppression de certains câblages de sécurité.

5.4 - Réalisation du système

5.4.1 - Technologie

5.4.1.1 - Protection des liaisons

L'évolution des avions d'armes conduit à des protections des liaisons plus poussées :

- sensibilité des liaisons numériques
- structures des avions en matériaux non métalliques
- environnement radioélectrique des avions d'armes de plus en plus sévère.

Ceci impose :

- des liaisons numériques transitant sur paires torsadées blindées spéciales avec continuité de blindage parfaite y compris au passage des prises,
- liaisons à large bande passante par câbles coaxiaux avec passages coaxiaux au niveau des prises et si possible blindage triaxial conformément au STANAG 3350,
- éventuellement remplacement des liaisons numériques électriques par des liaisons numériques à fibres optiques ; les transcodages électrique optique se font alors au niveau des prises terminales.

Ces conditions conduisent encore plus à souhaiter une minimisation du nombre de liaisons filaires vers les points d'emport qui sont des points géographiques particulièrement perturbés.

5.4.1.2 - Prises

Les prises à installer aux points d'emport (à la fois sur l'avion - sur les pylones et adaptateurs - sur les charges externes elles mêmes) doivent être standardisées et répondre aux critères suivants :

- ségrégation des lignes d'autorisation de tir : séparation métallique (séparation des champs électrique et magnétique) dans la même prise ou prise séparée,
- passages spéciaux pour les paires torsadées blindées des lignes numériques,
- passages coaxiaux, et si possible triaxiaux, pour les liaisons à large bande passante.

Ces prises peuvent être développées à partir de prises type DBAS existantes et comportant en particulier des passages pour paires numériques.

5.4.1.3 - Matériels électroniques à installer au niveau des points d'emport

Les conditions d'environnement au niveau des points d'emport sont très sévères (en particulier pour la température et les vibrations). Par ailleurs, les volumes disponibles pour installer de tels équipements dans des pylones ou adaptateurs sont très faibles ; il est donc indispensable que les composants utilisés soient largement intégrés et tiennent aux hautes températures et niveaux de vibration élevés ; l'étude thermique de ces équipements doit être particulièrement soignée.

5.4.2 - Gestion de l'ensembla

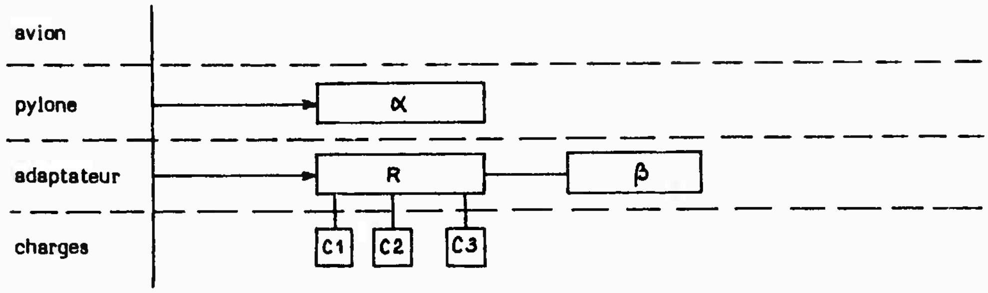
5.4.2.1 - Organe gérant

Le ou les organe(s) gérant(s) est (ou sont) un (ou plusieurs) calculateur(s) quelconque(s) du système d'arme soit spécialement prévu(s) pour la gestion de l'armement soit également utilisé(s) à d'autras tâches. Afin d'avoir le minimum de redondance nécessaire pour les problèmes de tir, il faut qu'au moins une partie de la gestion soit doublée (soit bi procasseur - soit deux calculteurs).

5.4.2.2 - Adressage

L'avion fournit une adresse à chaque point d'amport (deux valeurs de référence : isolé et masse structure) fournis par cinq fils. Au niveau de chaqua point d'emport, l'adresse évolue en suivant une loi précise très simplement réalisable matériellement :

A : adresse fournie par l'avion



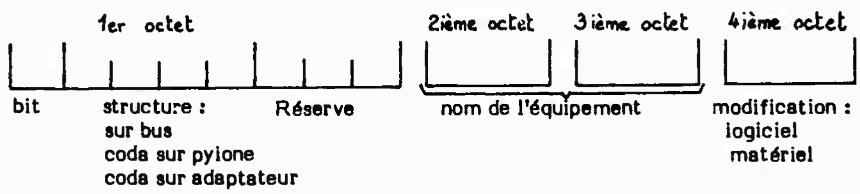
. α prend l'adresse A fournie par l'avion
. β prend l'edresse (A + 1)
. C_1 prend l'adresse (A + 2)
. C_2 prend l'adresse (A + 3)
. etc...

(A + 1) : signifie adresse suivante dans la suite.

La répartition est feite par la fonction R située dans l'edaptateur lorsqu'il y a plusieurs charges sous le même point d'emport

5.4.2.3- Identification des charges

Chaque charga et chaque équipement sur le bus numérique eu niveau des points d'emport fournissent leur code d'identification sous le forme d'un ou plusieurs mots de 32 bits composés comme suit :



la nom de l'équipamant est composé :

- d'une catégorie (3 bits) : missile, bomba, ECM, etc...
- d'un numéro d'ordra.

5.4.3 - Liaisons numériques particulières

Pour certaines armes, il sara nécassaire de dévalopper une liaison particulière extrèmament simplifiéa ; par exemple s'il est nécessaire de transmettre des informations à das roquettes, ellas peuvent être transmises par induction, il n'y a alors pas de prisa électrique sur les roquettes.

Par ailleurs, un volume (très petit) est réservé dans les pylones pour les liaisons particulières. Par exemple, si le bus numérique da l'avion est de type GINA, un transcodage GINA 1553 B peut être installé dans ce volume ; ceci permat d'emporter des charges utilisant le standard 1553 B sur les avions utilisant le standard GINA sans aucune modification matérielle de l'avion, seules des modifications de logiciel sont nécessaires.

6 - COMPARAISON AVEC LE PROJET DE STANAG 3837

STANAG 3837	PROPOSITION
- dépend de l'architecture interne SNA . BUS REDONDANT . BUS 1553	- ne dépend par de l'architecture interne SNA . bus non obligatoirement redondant . TYPE DE BUS : non spécifié
- pas de ségrégation de l'autorisation de tir par rapport aux alimentations	- autorisation de tir électromagnétiquement séparée des alimentations
- sécurité uniquement assurée par doublage de la ligne numérique	- sécurité assurée par discrets
- pas de protection particulière des câblages contre les perturbations radioélectriques	- protection des liaisons contre les perturbations radioélectriques
- liaison par fibre optique en plus du bus électrique	- bus optique à la place du bus électrique (transcodage dans la prise)
- le largage détresse nécessite la ligne numérique	- le largage détresse est indépendant de la ligne numérique
- pas de règle de progression d'adressage	- règle de progression d'adressage
- pas de règle d'identification des charges	- règle d'identification des charges
- architecture avec points d'emports en dérivation	- préférence (mais pas d'obligation) pour une structure en étoile pour séparer les problèmes liés à chaque point d'emport.

7 - EVOLUTIVITE DE LA SOLUTION PROPOSEE

La solution présentée peut être appliquée progressivement sur les avions en suivant l'ordre suivant à condition que chaque élément de la chaîne soit réalisé de façon modulaire, chaque module pouvant être remplacé par un module plus évolué en fonction de l'avancement des études, réalisations et technologies.

7.1 - Ligne numérique

La première chose à standardiser est la ligne numérique, sans redondance dans un premier temps.

Ceci implique en particulier dès le départ d'avoir établi les règles d'adressage et d'identification.

L'augmentation du nombre de charges externes abonnées au bus augmentera progressivement. Cela conduira à faire évoluer le répartiteur de bus : au départ c'est un répéteur de bus, puis un coupleur de sous bus simple, puis éventuellement un coupleur de sous bus multiple.

L'interfaçage de chaque charge externe ou équipement doit se faire par un module technologique, interchangeable (carte ou composants, etc...) de façon à pouvoir changer le type de liaison numérique très rapidement.

7.2 - Aiguillages analogiques

C'est chronologiquement le deuxième problème qu'il convient de standardiser. Les matrices d'aiguillages peuvent, dans un premier temps, être simples (1 parmi N) puis plus complexes (n parmi N). L'un des problèmes lié à l'aiguillage, est la quantité de câbles arrivant à un point unique ; il peut donc être intéressant de hiérarchiser cet aiguillage afin de mieux répartir les problèmes de connectique à l'intérieur de l'avion. Pour chaque signal vers chaque point d'emport, il faut donc un module technologique séparé qui pourra évoluer dans le temps en fonction de la complexité demandée et des possibilités technologiques. Certaines liaisons nécessitant aujourd'hui des aiguillages permettent d'évoluer vers des bus numériques spécifiques (par exemple bus vidéo sur liaison à fibre optique).

7.3 - Tir

L'utilisation da la liaison numérique pour la tir le plus en aval possible dans le circuit, c'est-à-dire au nivaau des pylones, nécassite la développemant de composants très intégrés fonctionnant dans un environnement très sévère. Ceci peut être fait dans un troisième temps sans avoir à modifier ni les charges externes, ni les câblages de l'avion.

Cet équipament devra également être réalisé de manière modulaire en particulier de façon à pouvoir réduire, par la suite, la nombre da sécurités par discret.

7.4 - Sécurités

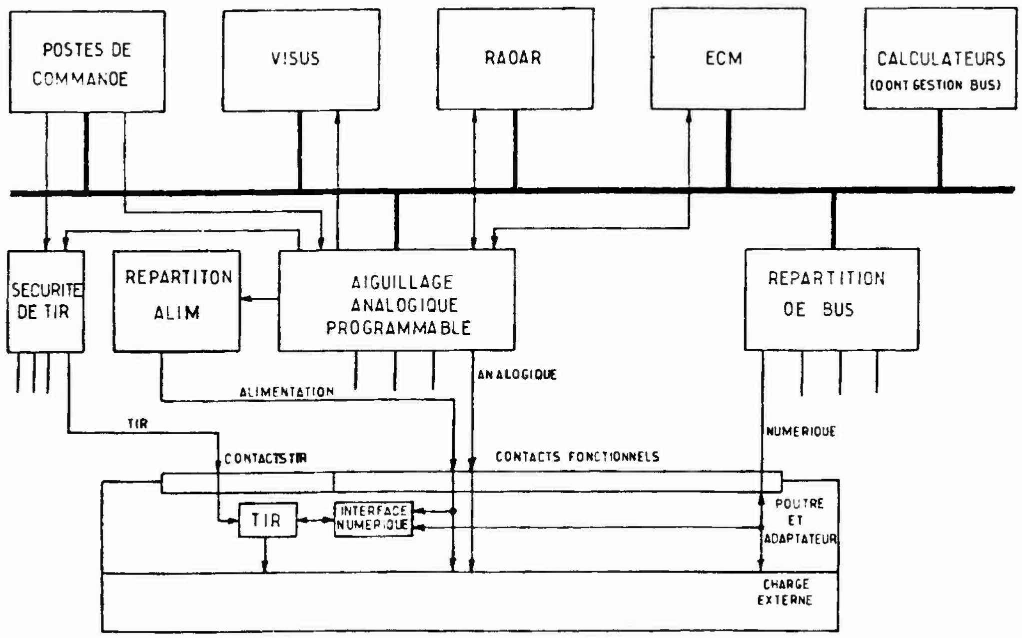
Dans un premier temps les sécurités sont assurées par des liaisons spécifiques. Les évolutions technologiques peuvent permettre des redondances multiples des circuits d'interface de la liaison numérique avec vote(s). Les sécurités par discrets pourront alors être supprimées par remplacement des interfaces dans les équipaments concernés (pylones - adaptateurs - charges externes).

8 - MAINTENANCE

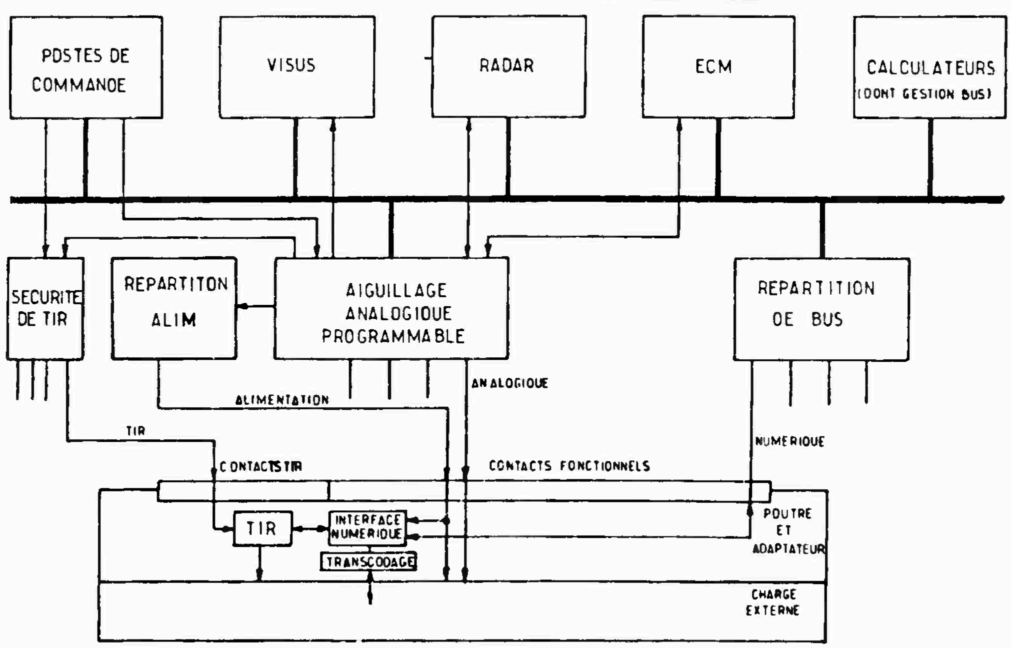
La standardisation des interfaces des charges axternes rend possible l'utilisation des matériels de maintenance standardisés qui sont les mêmes quelle que soit la charge externe installée sous l'avion. Par ailleurs, les mêmes matériels peuvent servir à tester l'installation avion et les charges externes elles-mêmes. Il est alors facilement envisageable de réaliser la maintenance de l'avion sans matériel extérieur (maintenance intégrée). La maintenance intégrée permet également de faire la maintenance des charges externes installées sous avion sans utiliser de matériel supplémentaire, des logiciels sont intégrés dans les calculateurs de l'avion.

ANNEXE

CAS DES NOUVELLES CHARGES



CAS OES CHARGES A LIAISON SPECIFIQUE



DISCUSSION

R.Cope, UK

In the diagram in your Annex, a connection is shown between the SMS and the computer and during the presentation you spoke of automatic weapon identification. Can you tell us whether, and if so to what extent, this information is made available to the operational flight programmes, for use in configuration warning and flight control calculations, for example?

Réponse d'Auteur

L'information d'identification est principalement utilisée pour l'initialisation au sol mais est accessible à tout moment pendant le vol. Les contrôles du centrage et de symétrie de masse utilisent une combinaison de l'information d'identification et de l'information de présence de charge.

SUMMARY OF SESSION II
AVIONICS AND SYSTEM STATE-OF-THE-ART

by

W.F.Ball
Session Chairman

The papers of Session II primarily dealt with the subject of avionic systems integration, fault-tolerant design approaches, fault detection and bus structured systems architectures.

The first paper of this session was entitled "Towards the Functional Partitioning of Highly-Integrated, Fault-Tolerant Avionics Signal Processors", by Mr J.A.Rey of Northrop Corporation. In his paper, Mr Rey viewed the Fighter/Attack aircraft of the future as a highly integrated weapon system, integrating (vice stand alone) functions/subsystems such as penetration, target acquisition, weapon delivery, threat detection and suppression and flight/engine control. Especially with the advent of VHSIC/VLSIC processors in the near future, it will be possible to move toward fault tolerant computing architectures that both assure safety of flight and provide a significant advance in operational capability. Mr Rey discussed issues relating to the architecture of such near future systems wherein sensor blending/data fusion/high speed operation are to be successfully achieved. He also provided some consideration of the reliability of such systems.

The second paper by Mr R.C.Drummond and J.L.Looper of McDonnell Aircraft was entitled, "Advanced F/A-18A Avionics". The paper was presented by Mr Looper. This paper described in some detail the current F/A-18 and indicated some of the possible enhancements to be made on the aircraft in the future. The growth capacity of the F/A-18 was discussed, reviewing the spare computer memory, excess electrical power, abundant cooling air and some remaining physical space. This will allow ease of expansion in capability in the future. A reconnaissance version of the aircraft is under development. Because of the flexibility and safety of the digital flight control system, the current design will serve as an excellent test bed for advanced flight control studies. Capitalizing on the built-in growth potential of the F/A-18, advanced aircraft programs aimed at exploitation of these capabilities are underway.

Paper number three, "DEF STAN 00-18: A Family of Compatible Digital Interface Standards", by D.R.Bracknell and A.A.Callaway of RAE Farnborough, was read by Mr D.Oldfield, also of Farnborough. This paper provided a detailed look at the UK MOD Defence Standard (DEF STAN 00-18) which is the definitive UK Standard for digital interfaces in aircraft. Four standards, under the DEF STAN 00-18, have been published so far by the joint MOD(PE)/Industry Data Transmission Standards Committee (DTSC). The four standards published so far are: Multiplex Data Bus Standard (MIL STD 1553B has been redrafted into the DEF STAN 00-18 format, remaining technically identical and preserving compatibility), Single-Source, Single/Multiple sink Interface Standard (a more simple standard than 1553B), Discrete Signal Interface Standard (Time-critical Signaling, non-time-critical signaling and low power switching), and Fibre Optic Transmission Standard (although many standards and definitions are given, further work is needed). Additional work by DTSC will take into account the accommodation of advances in technology and the development of new requirements. This work has laid a good basis for UK aircraft work and for full participation in international standardization activities.

The next paper, by Mr W.H.Hall of British Aerospace, was concerned with the subject "Techniques for Interbus Communication in a Multibus Avionic System". Mr Hall described the work that British Aerospace (Brough) has concentrated on relating to interbus communication. Whereas his company has worked with MIL STD 1553 for some four years, their work on an Advanced Systems Demonstrator Rig for MOD has pointed out the lack of definition of interfacing between buses (a typical problem encountered in developing multibus architectures). Interbus message types to be dealt with include Bus Controller (BC) to Remote Terminal (RT) with BC & RT on different buses and RT to RT where the two RTs were on separate buses. Both synchronous and asynchronous message transfers were considered. The paper suggests that this work can be used to extend the 1553 message transfer protocol to work in a multibus environment.

Paper five was entitled "A Video Bus for Weapons Systems Integration" by Dr L.Currier and E.Miles, General Dynamics, Fort Worth. Dr Currier noted that with the advent of MIL-STD-1760 (Standard Stores Interface), while system transparency is preserved with minimal restrictions imposed on the airframe manufacturer, it would still be very difficult to meet the standard, physically and electrically, with discrete wiring. Especially this is the case with the wing sizes of modern fighter sized aircraft. The standard calls for two, bi-directional video lines at each store station. Dr Currier described a video bus approach which is under development. This approach will permit a common "video highway" with large bandwidth to allow multiple simultaneous channels. Remotely tuneable modems allow access to the bus.

The sixth paper of this session was written by J.Ostgaard and A.Zann of Wright Patterson AFB (AFAL). The subject was: "Network Communications for a Distributed Avionics System". This paper dealt with the issue of evaluating network communication techniques to arrive at promising candidate approaches for 1990's era advanced avionics architectures. The basic philosophy of the architectures to be experienced in that timeframe was discussed. To deal with these architectures, the paper suggests that MIL-STD-1553B is too limited and that a new data bus needs to be developed that incorporates 1553B and that can address the future requirements. Mr Ostgaard presented a detailed review at his evaluation criteria and methodology. After looking at the evaluation results, the authors suggest that an enhanced 1553B approach might be the best choice, lowest risk approach for the future. The study described in the paper is aimed at influencing future standards for bussing.

The seventh paper, "Avionics Fault Tree Analyzer", by M.E.Harris, McDonnell Aircraft, gave a description of a Microprocessor controlled, ground-based test set for the F/A-18 aircraft. This equipment, which is man-portable, communicates with, exercises, interrogates and diagnoses the Avionics Subsystem in the aircraft. In some cases, the AFTA isolates wiring as well as electronic faults. The AFTA interfaces with the aircraft via a single connector and has an operator interface via a plasma display and a touch panel. It appears that studies are underway to incorporate the AFTA function within the aircraft as future memory and computer/avionics capability will permit.

The eighth paper by M.E.L.Courtois of Avions Marcel Dassault-Breguet Aviaion, was entitled, "Maintenance Premier Echelon Intégrée dans les Systèmes d'Armes". This paper dealt with first level integrated maintenance for armament systems, as indicated in the title. Mr Courtois described an integrated maintenance approach that produced many advantages. It allows for growth in the digital hardware. It permits investigation of failures without flight simulation and does so without external hardware, except where required by individual weapons systems. The method allows investigation of failures in flight (some of which are not always evident on the ground). Likewise, it permits instantaneous search and validate functional channels related to the armament system. This test capability is built-in to systems such as the Mirage 2000 utilizing the "Digibus" mechanization and is done so with 25K words of memory.

The final paper of Session II was a very interesting paper presented by Dr S.J.Kubina of Concordia University, Montreal and P.Bhartia, DRE, Ottawa. The topic was concerned with "Computer Graphics Techniques for Aircraft EMC Analysis and Design". While the subject was computer graphics, the presentation itself was well illustrated with dual 35 mm slides that, in themselves were graphically illustrative. Dr Kubina described an effective computer-aided system for the prediction of the potential interaction between avionics systems with particular attention paid in the paper to antenna-to-antenna coupling. The strength of Dr Kubina's approach lies in the effective graphics visibility that is afforded to the weapons/avionics system designer. This visibility of the entire EMI interaction matrix produces an insight into the design/physical/electrical characteristics of the aircraft heretofore not available. Because of the visual aiding presented to the designer, it is clear that this is indeed, a very powerful tool.

TOWARDS THE FUNCTIONAL PARTITIONING OF HIGHLY INTEGRATED, FAULT TOLERANT AVIONICS SIGNAL PROCESSORS

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ABSTRACT

Avionics systems for new interdiction fighter aircraft require a high degree of integration, translated into automation for crew operations, of such formerly diverse subsystems of penetration, target acquisition, weapon delivery, threat detection and suppression and flight/propulsion control. Also coupled into this is the infusion of VHSIC/VSLIC. All this implies the need for a fault tolerant system to ensure flight safety and high operational ability. This paper discusses some of the partitioning (configuration)issues involved in the integration process. Specifically, this paper addresses itself to the issues involved with the functional partitioning into "generic" high speed signal processors and how this partitioning will cross some of the traditional interfaces between such things as flight control systems and avionics systems and subsystems within the avionic suite. Of special interest is the partitioning for sensor blending/data fusion/hi-speed data buses as pertains to terrain following/terrain avoidance function and how the critical path computations can be made fault tolerant and/or allow for graceful degradation so that flight/mission safety is assured. Also discussed are the methods for computing reliability values based on these new configurations so that fault tolerant evaluations methods, such as the Markow process, may more realistically be computed.

CONSIDERATIONS AND IMPLICATIONS FOR ADVANCED TACTICAL FIGHTER AVIONICS

Requires a very high degree of integration due to automation of crew functions (reduction of crew work-load)

Each subset was built (manufactured) by a supplier who had all knowledge of how to make his subset work. He was not concerned how other subsets within the aircraft worked, rather, he maximized his own subset both technically and from a business point of view------For example a radar manufacturer did not process any data from a FLIR or Digital Map unless he felt he needed it then he put it in his own sensor/processor and this is what he delivered to the integrator. The integrator only worried how to get it into the AC and how to train the pilot (until now basically an airplane driver) how to use it. With the advent of cynergism each subset is no longer standalone. The prime integrator is responsible for "putting it all together" and cannot rely on subset manufactures to solve his (the prime's) weapon system problems. Hence we have such things as "sensor blending". The cynergism of a multiple set of sensors to provide solution oriented (artificial intellegence) data to the crew member dictates the blending of diverse information at the earliest possible point within the system.

CONSIDERATIONS & IMPLICATIONS

SCOPE-------------------THE PARTITIONING & DISTRIBUTION OF SIGNAL PROCESSING TASKS FOR AN INTEGRATED FIGHTER/ATTACK AIRCRAFT AVIONIC SYSTEM.

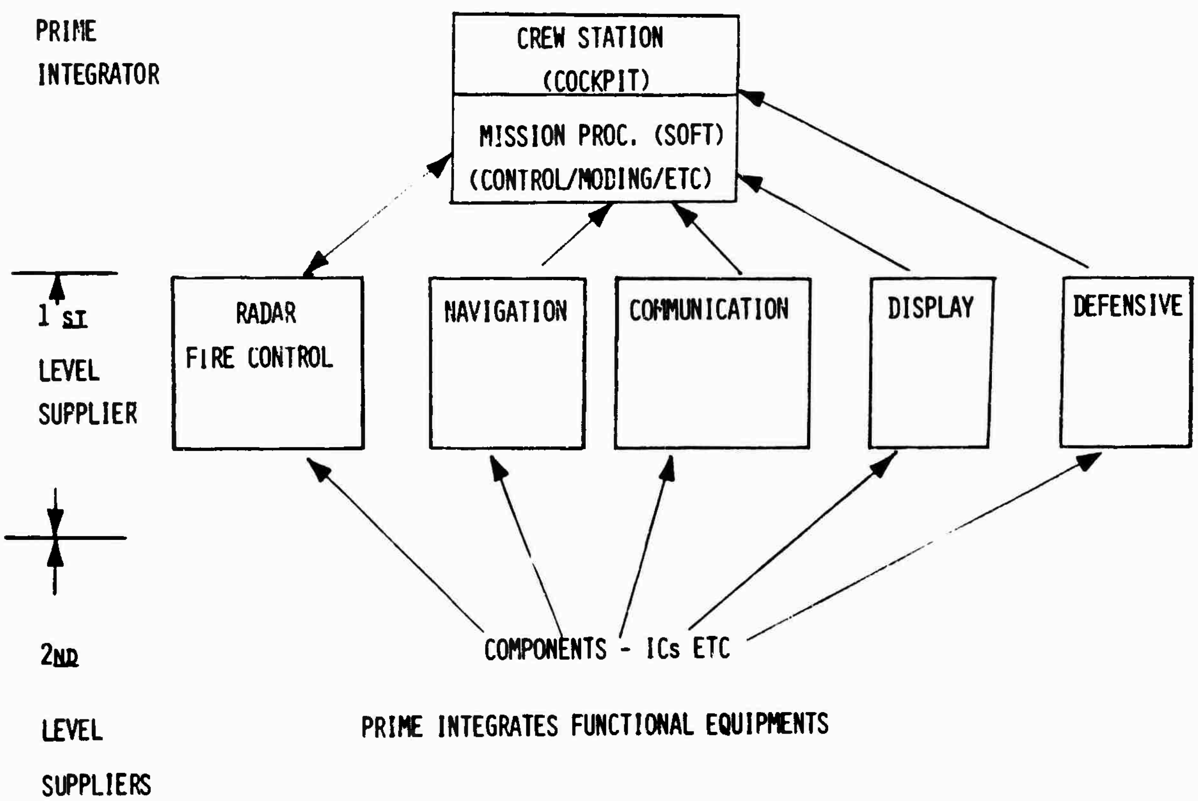
WHY---------------------TRADITIONALLY, SIGNAL PROCESSING WAS AN INTEGRAL PART OF A FUNCTIONAL SUBSETS SUCH AS A RADAR, FLIR, INERTIAL SET.

NOW---------------------SIGNAL PROCESSING--------MANY TIMES CANNOT BE DISTINGUISHED FROM DATA PROCESSING-----------IS NO LONGER UNIQUELY INTEGRAL TO SUBSETS.

PRESENT METHOD OF INTEGRATION

PRIME ACQUIRES COMPLETE OR NEARLY COMPLETE FUNCTIONAL EQUIPMENT SETS THEN INTEGRATES EACH FUNCTION.

MAJOR CONSIDERATION IS THAT THE SYSTEM PERFORMANCE IS MAINLY DETERMINED BY THE INDIVIDUAL PERFORMANCE OF EQUIPMENT SET WITH THE SYSTEM INTEGRATION PRIMARILY CONFINED TO CONTROL AND DISPLAY.

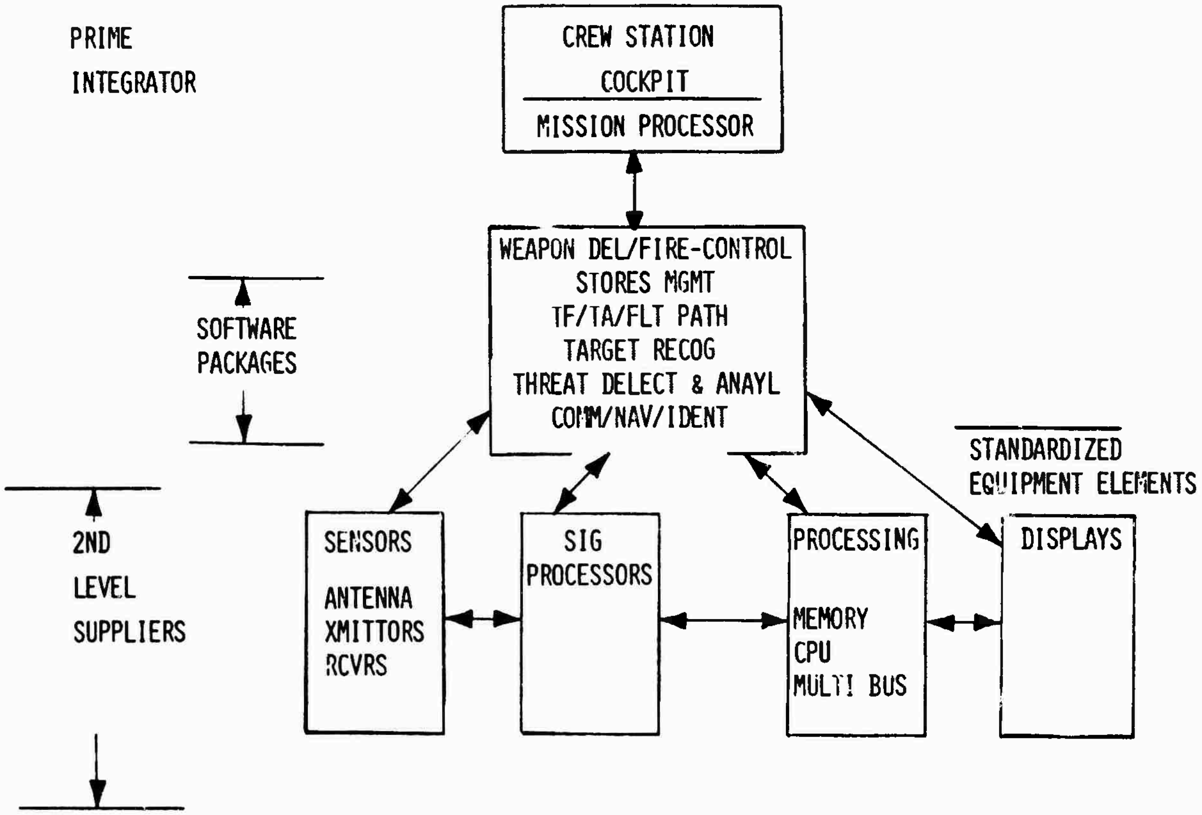


PRIME INTEGRATES FUNCTIONAL EQUIPMENTS

NEW METHOD OF INTEGRATION

THE PRIME WILL ACQUIRE VARIOUS SENSOR ELEMENTS FROM SUPPLIERS: PROCESSING ELEMENTS FROM SUPPLIERS AND THEN THROUGH THE PROCESS OF DEVELOPING SOFTWARE INTEGRATE AN AVIONIC SYSTEM.

THIS METHOD WILL REQUIRE A NEW METHOD OF DEALING WITH DIFFERENT TYPES OF SUPPLIERS, NAMELY SUPPLIERS OF SOFTWARE AND ALGORITHIMS. MOSTLY THE FUNCTIONALITY OF THE EQUIPMENT ELEMENTS WILL BE SEPARATED FROM THE SYSTEM FUNCTIONS. I.E. EQUIPMENT FUNCTIONS WILL BE TO SENSE SIGNALS AND SYSTEM FUNCTIONS WILL BE TO PERFORM TERRAIN FOLLOWING.



INCLUDES IMBEDDED SOFTWARE

PRIME BRINGS TOGETHER STANDARDIZED
EQUIPMENT ELEMENTS - CAUSES SOFTWARE

PROBLEM POSED TO PRIME SYSTEM INTEGRATOR

New avionic systems will not be implemented with the traditional functional subsets. Most likely subsets will be identified according to the following:

Sensor (Offensive)---------- \
Sensor (Defensive) -------- / Antenna and RF Sections

Processing elements:

Signal Processing
Data and Control Processing
Data Transfer
Storage
Control/Display

Is the distribution or the assignment of the System Tasks to be done by:

- As in the past by individual processor with the limits being throughput and memory size?
- As in the past by the physical entity itself?

No to both of the above.

- \- First some issues need to be identified.
  - What constitutes a processor
  - What constitutes connectivity.
  - What is embedded vs core

There are others but these will do for now.

PROBLEMS POSED TO PRIME SYSTEM INTEGRATOR

- WHAT IS PARTITIONING

- WHAT IS FAULT TOLERANCE

- HOW IS IT DONE

- BY WHO IS IT DONE

WHAT IS A PROCESSOR

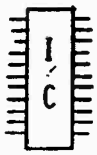
- Is it a multi CPU device.
- Is it a complete entity; self contained with its own memory and power supply - VHSIC.
- Is it to be generic.
- How is it to be packaged -------

  - One per box?
  - Distributed power supply (power multiplex)
  - How is it qualified to present MIL-E-5400? (is MIL-E-5400 still valid)

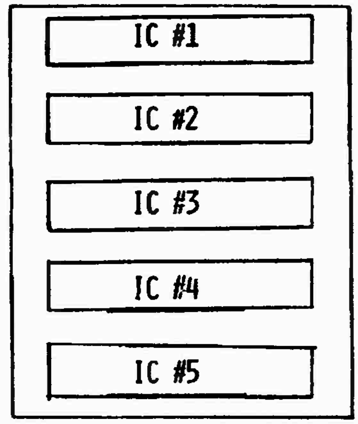
WHAT FUNCTIONS WILL THESE PROCESSORS PERFORM

- SIGNAL PROCESSING FOR SPECIFIC SENSOR TYPES
  - FLIR
  - RADAR (X. BAND: MILLIMETER WAVE)
  - DIGITAL (MAP DATA)
  - CO_2 LASER
- HIGH SPEED MIXING OF SENSOR/MAP DATA
- HIGH SPEED DETECTION & RECOGNITION OF THREAT DATA AND CORRELATION TO MAP OF EITHER BRIEFED ON UN-BRIEFED THREATS.

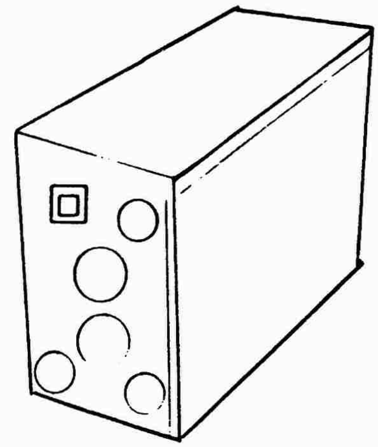
WHAT IS A PROCESSOR



SINGLE IC
PROCESSOR



MOTHER BOARD WITH
MANY PROCESSOR



ATR BOX
WITH MANY MOTHER BOARDS

WHEN PARTITIONING TASKS, WHAT IS THE CONSIDERED TO BE THE BASIC BUILDING BLOCK?

WHAT IS FAULT TOLERANCE

- REDUNDANT — if so to what level triple - quad - etc.

- Not hardware but software redundant
  - functionally equivalent but different
  - performance levels - alternate paths

- Drivers - come from mission requirements analysis

  Sorted out by:

  - Vehicle Saftey
  - Mission Critical
  - Mission Desirable

WHAT FUNCTIONS WILL THESE PROCESSORS PERFORM

- SIGNAL PROCESSING FOR SPECIFIC SENSOR TYPES
  - FLIR
  - RADAR (X. BAND: MILLIMETER WAVE)
  - DIGITAL (MAP DATA)
  - CO_2 LAZER
- HIGH SPEED MIXING OF SENSOR/MAP DATA
- HIGH SPEED DETECTION & RECOGNITION OF THREAT DATA AND CORRELATION TO MAP OF EITHER BRIEFED ON UN-BRIEFED THREATS.

HOW DO THESE FUNCTIONS RELATE TO MISSION

THE "PRIME" IS RESPONSIBLE FOR PERFORMANCE OF THE MISSION FUNCTIONS. IN RELATING EQUIPMENT OPERATION TO MISSION FUNCTION, THE PRIME WILL DETERMINE WHAT ALGORITHIMS ARE TO BE IMPLEMENTED, BY WHO AND WHERE THEY WILL BE HOSTED. THIS IS THE PARTITIONING PROCESS. THE PRIME WILL USE AS HIS DRIVING ELEMENTS SUCH THINGS AS:

- OVERALL RELIABILITY OF THE ELEMENTS WHICH PERFORM THE FUNCTIONS.
- FLIGHT CRITICAL, MISSION CRITICAL, ETC.
- ALTERNATIVE PROCESSES------I.E. MORE THAN ONE WAY TO LOCATE A TARGET USING ALTERNATE SENSORS AND PROCESSING PATHS.

HOW DO THESE FUNCTIONS RELATE TO MISSION

- THIS IS THE CRUX OF WHY THE PRIME BECOMES INTERESTED.

LET US RELATE TO A MISSION PHASE

LOW LEVEL PENETRATION

FUNCTIONS:

TERRAIN FOLLOWING/TERRAIN AVOIDANCE
AUTOMATIC FLIGHT PATH GENERATION
AUTOMATIC THREAT DETECTION/AVOIDANCE/SUPPRESSION
AUTOMATIC TARGET RECOGNITION
DISPLAY GENERATION

ALL THIS REQUIRES HIGH-SPEED PROCESSORS AND IN SOME MEASURE FAULT TOLERANCE

WHAT IS FAULT TOLERANCE

IF THE SYSTEM-----SIGNAL PROCESSOR-----IS TO BE FAULT TOLERANT IT IS NECESSARY TO DEFINE WHAT IT IS FAULT TOLERANT TO:

- FIRST, AS ALREADY MENTIONED, THE MISSION FUNCTION NEEDS TO BE CATEGORIZED AS TO CRITICALITY.

  THEN THE RELIABILITY OF THE ELEMENT IS EXAMINED AND IF THAT RELIABILITY IS NOT ADAQUATE TO MEET THE SYSTEM AVAILABILITY----SOME KIND OF FAULT TOLERANCE IS THEN REQUIRED.

- WHAT ALSO NEEDS TO BE ADDRESSED IS SOFTWARE RELIABILITY. THIS IS THE LATENCY PROBLEM ATTRIBUTED TO UNFOUND PROBLEMS IN THE SOFTWARE. THEREFORE "COVERAGE" OF SOFTWARE FAULTS IS REQUIRED FOR VEHICLE AND MISSION CRITICAL FUNCTIONS.

WHAT IS FAULT TOLERANCE

- DRIVERS - IS PARTITIONED FUNCTION INVOLVED IN:

  VEHICLE SAFTEY
  MISSION CRITICAL
  MISSION DESIRABLE

- ESTIMATES OF RELIABILITY - IC LEVEL
  MOTHER BOARD LEVEL
  BOX LEVEL

- HOW TO BE TOLERANT

REDUNDANCY	FUNCTIONAL ALLERNATIVE
HARDWARE ALONE	MOSTLY SOFTWARE
SOFTWARE ALONE	ASSIGNED TO ALTERNATE
	(HOT-COLD SPARES)
	PROCESSORS WITH DEGRADED
	PERFORMANCE
	(DYNAMIC RECONFIGURATION)

HOW IS IT DONE

- DYNAMIC RECONFIGURATION
  - HAVE A MULTIPLE SET OF PROCESSORS WHICH CAN BE DYNAMICALLY RECONFIGURED (BY A SYSTEM EXECUTIVE) TO ACCOMODATE FAILURES (IMPROPER PERFORMANCE)
- THIS INDICATES THAT EACH PROCESSOR IS A CLONE OF THE OTHER AND ONLY SOFTWARE ASSIGNED AT ANY GIVEN TIME IS DIFFERENT - CHARACTERISTICS OF WHICH ARE:

GENERIC CPU	(INSTRUCTION SET & WORD LENGTH)
DYNAMIC MEMORY	(LOADABLE FROM MASS STORAGE)
HIGH SPEED BUS	(FOR INTERPROCESSOR - AND BULK STORAGE - DATA TRANSFER)
MULTIPLEXED POWER BUS	(TO AVOID SINGLE POINTS OR FAILURE CHAINS)

BY WHO WILL THIS BE DONE

- MOSTLY BY THE PRIME -

  PRIME IS RESPONSIBLE FOR MISSION PERFORMANCE

ASSISTED BY:

- SOFTWARE (ALGORITHIM DEVELOPERS) HOUSES
- EQUIPMENT ALEMENT SUPPLIERS

SUMMARY

- NEW BURDEN PLACED ON PRIMES
- NEED TO DEVELOP NEW WAYS TO WORK WITH SECOND LEVEL SUPPLIERS.
- NEED TO UNDERSTAND HOW TO DETERMINE "ELEMENT LEVEL" RELIABILITY FOR PURPOSES.
  - MARKOV MODELING (SYSTEM PERFORMANCE LEVEL)
  - DEGREE (COVERAGE) AND METHODS OF FAULT TOLERANCE
  - FUNCTIONAL PARTIONING

DISCUSSION

L.Crovella, It

Do you think that your approach on processors partitioning is compatible and will merge in the future into the avionic system architecture, as described by Mr G.R.England in the first paper of this symposium?

Author's Reply

Yes, if the signal processor is a "common-module" such as shown by Mr England. The merging into the system architecture would be performed during the design trade-off analysis for the core architecture/topology.

N.J.B.Young, UK

In your presentation you talked about achieving fault tolerance by being able to down-load a program to another processor (from a mass storage medium) when the first processor was found to be faulty. There are of course many other methods for achieving fault tolerance. Is the method you mentioned your preferred technique or is it just an example of methods under consideration?

Author's Reply

No this is not a preferred technique – it is only one example of many which would be available for implementation. The method selected would become part of the avionic set core architecture/topology.

ADVANCED F/A-18 AVIONICS

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SUMMARY

The F/A-18 Hornet is a single-seat, twin-engine aircraft designed to fulfill fighter and light attack roles for the U.S. ~~United States~~ Navy and Marine Corps, and is being purchased abroad ~~by Canada, Australia and Spain.~~ It has a very capable multimission weapon system, integrated so a single pilot can perform both fighter and attack missions.

The challenge of multimission capability is to provide the necessary weapon system elements for effective air-to-air and air-to-surface weapons delivery without requiring a major flight line change each time the aircraft is reconfigured with armament. The answers for the multimission Hornet are digital technology and extensive system integration. High reliability, large scale integrated circuits and microprocessors are employed throughout the digital avionics suite. Integration among avionic subsystems is accomplished over the MIL-STD-1553A dual digital multiplex bus under control of two mission computers. As illustrated in Figure 1, the Hornet has significant growth potential in addition to its present capabilities. Growth capacity includes spare computer memory, electrical power, cooling air and physical space.

GROWTH POTENTIAL IS

CAPABILITY	PLUS	FLEXIBILITY	PLUS	CAPACITY
DIGITAL RADAR • AIR-TO-AIR • AIR-TO-GROUND FLIR LASER TRACKER COMPUTERS DIGITAL FLIGHT CONTROL CRT DISPLAYS PRIMARY HUD INTERNAL ECM COMPLETE CNI	+	DIGITAL INTERFACES MULTIPLEX DATA TRANSFER PROGRAMMABILITY • SENSORS • MISSION COMPUTERS • CONTROLS/DISPLAYS • FLIGHT CONTROLS	+	VOLUME POWER COOLING SOFTWARE MULTIPLEX DATA

AD18-5350
GP33-0141-1

FIGURE 1

The production F/A-18 configuration is being improved with the addition of current developments such as the Advanced Medium Range Air to Air Missile (AMRAAM), Airborne Self Protect Jammer ~~(ASPJ)~~ and the Joint Tactical Information Distribution System (JTIDS). A reconnaissance engineering program is under way, which will modify the nose of a test airplane to add cameras and an IR line scanner to the existing high resolution radar and FLIR. An all-environment attack variant is being studied, which will include a higher resolution radar, low altitude penetration enhancement, and automatic target recognition. The F/A-18 avionics are modern, integrated, and flexible, making extensive use of the power of digital computer technology. Significant growth potential is built in. Programs to exploit these capabilities are under way.

PRESENT AVIONICS CAPABILITY

The avionic challenge was to design a weapon system compatible with the relatively small airframe and not require a major flight line reconfiguration each time it was converted between air-to-air and air-to-surface roles. The answer for the Hornet is to use the advancements in digital avionics technology, more multiplexing of intersystem data, and more efficient integration to eliminate redundant equipment. For example, the F/A-18 has:

- o Programmable controls and displays integrated for one man operation.
- o A long range, all-altitude, all-aspect, programmable multimode radar with excellent look-down performance.
- o Single step selection for long range, short range and close-in combat firing with the Sparrow, Sidewinder, and internal 20mm cannon.
- o Accurate day and night air-to-surface delivery of conventional and guided weapons against land or sea targets.
- o Modularized mission software structure with MIL Standard 1553 dual multiplex bus.
- o A high authority, quad-digital, control-by-wire primary flight control system.

- Internal electronic warfare equipment for threat warning and defensive countermeasures.
- A self-contained inertial navigation system.
- Designed-in system reliability, maintainability, and survivability.
- Automatic in-flight maintenance data recording for avionics, engine and airframe.

The avionics suite is configured in seven functional groups, Figure 2. Most intersystem data are transferred over the 1 megahertz dual digital avionics multiplex bus, which is controlled by the mission computers. Three other multiplex buses provide specialized dedicated information flow between the stores management processor and the fuselage/wing station armament decoders, between the communication system controller and the up-front control, and between the flight control computers for redundancy management.

Eighteen of the subsystems in Figure 2 have primary processors which communicate directly on the avionics multiplex bus. There are 20 other microprocessors which are integrated either through the primary processor equipments or via separate discrete signals.

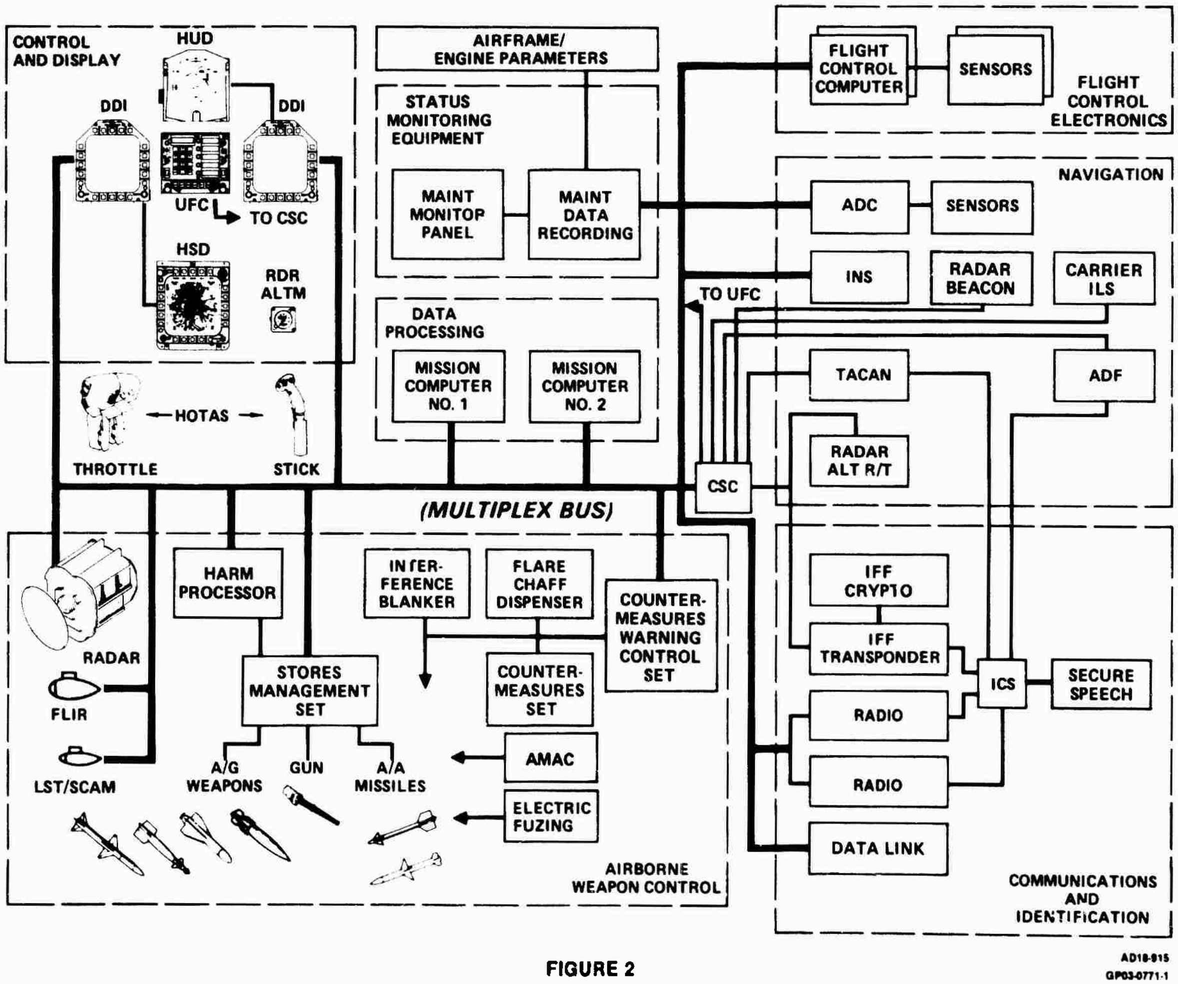


FIGURE 2
AVIONICS SYSTEM

Computations and System Architecture - Partitioning of the F/A-18 mission computations and decisions within the avionic system is done on the basic premise that is either sensor/equipment-oriented, or mission-oriented. Sensor/equipment oriented computations are primarily independent computations, such as inertial platform control, radar signal processing, display symbol generation, and air data calculations. Mission oriented computations include tasks such as air-to-air and air-to-surface steering and weapon firing computations, integrated cockpit display management, and selection of the best available parameters from various candidate sensors.

Cockpit Controls and Displays - The requirements for small size and good pilot visibility resulted in an instrument panel and console area 40% smaller than that in the A-7 attack aircraft or the F-4 fighter. To implement the multimission needs and to achieve one-man operability of the sensors and weapons, MCAIR employed computer-aided control and display techniques developed through extensive human engineering analysis, man-in-the-loop simulation and flight testing. Key elements are computer controlled real time programmable cathode ray tube (CRT) displays which present simultaneous target, weapons, sensor, and own ship flight information; computer placement of cockpit controls when and where they are needed; and automatic initialization of the displays, sensors and weapons for the selected mission mode.

MCAIR test pilots and an Air Crew Systems Advisory Panel made up of experienced USN/USMC pilots tested the designs and control/display formats throughout the development program, offering suggestions and reviewing alternate approaches to evolve the current design.

The resulting crew station, Figure 3, features a head-up display and three other multipurpose cathode ray displays driven by both mission computers, an integrated up-front control panel and numerous time critical/high "g" functions on the flight control stick and throttles.

The three head-down multifunction displays, which each have 20 programmable switches integrated around their display periphery, and the programmable up-front control, collectively replace the more than a dozen separate avionic control panels of previous aircraft. The HUD is the primary flight instrument for both navigation and combat, eliminating the large 4 inch ADI ball. The right hand multifunction display is the primary control/display for radar attacks. The left hand display is the primary control/display for EO and IR sensors, armament, and aircraft caution, advisory and built-in test functions. The Horizontal Indicator (HI) presents CRT-generated planview information superimposed on a color film projected moving map for navigation, updating, and sensor correlation.

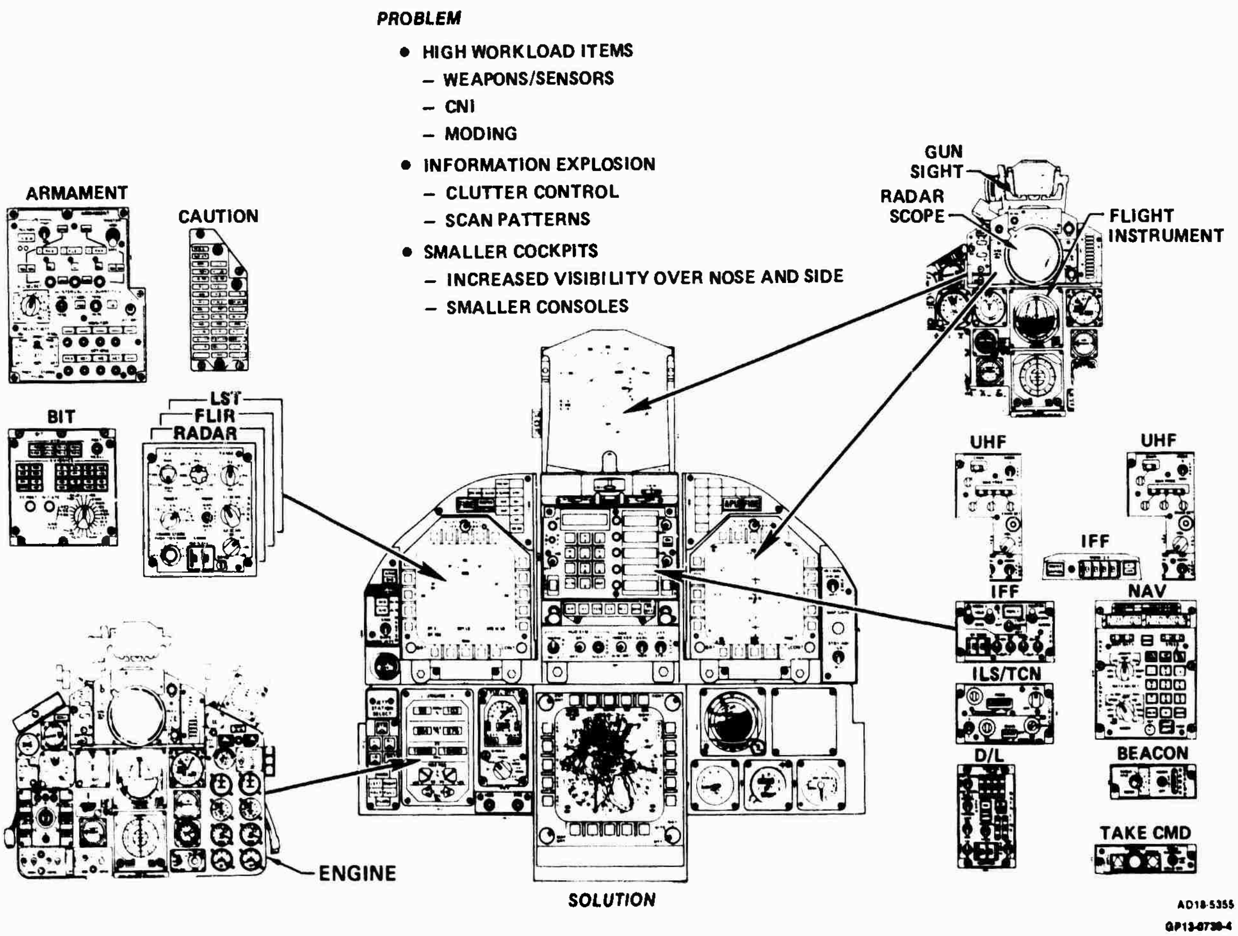


FIGURE 3
COCKPIT INTEGRATION

The three CRT displays use a MENU concept, Figure 4, to take advantage of software flexibility in the orientation of switches. As shown, the various modes have computer-driven submode nomenclature which becomes available when needed.

The left and right hand displays are identical. Each contains the symbol generators capable of driving up to two other displays (HUD and HI) depending upon mode complexity. Additionally, mission computer display management software has been designed so that the control/display functions of the left/right displays are interchangeable, allowing all of their functions to be selected on either display in flight.

The Hornet Hands-on-Throttle-and-Stick (HOTAS) concept provides computer assigned switches for weapon and sensor control during high "g" maneuvering and for time critical functions while maintaining full control of the aircraft. The HOTAS concept allows the pilot to perform complete visual and sensor aided gun and missile attacks, from target detection through weapon delivery without removing his hands from the stick or throttle. Similar functions are performed for air-to-surface attack.

The Target Designator Control (TDC) on the throttle is a force-sensitive switch which slews the sensor seekers and display designator symbol in any direction. Designation is accomplished by pressing and releasing the TDC switch. The TDC can also be used to select radar parameters such as mode, scan, azimuth and range scales.

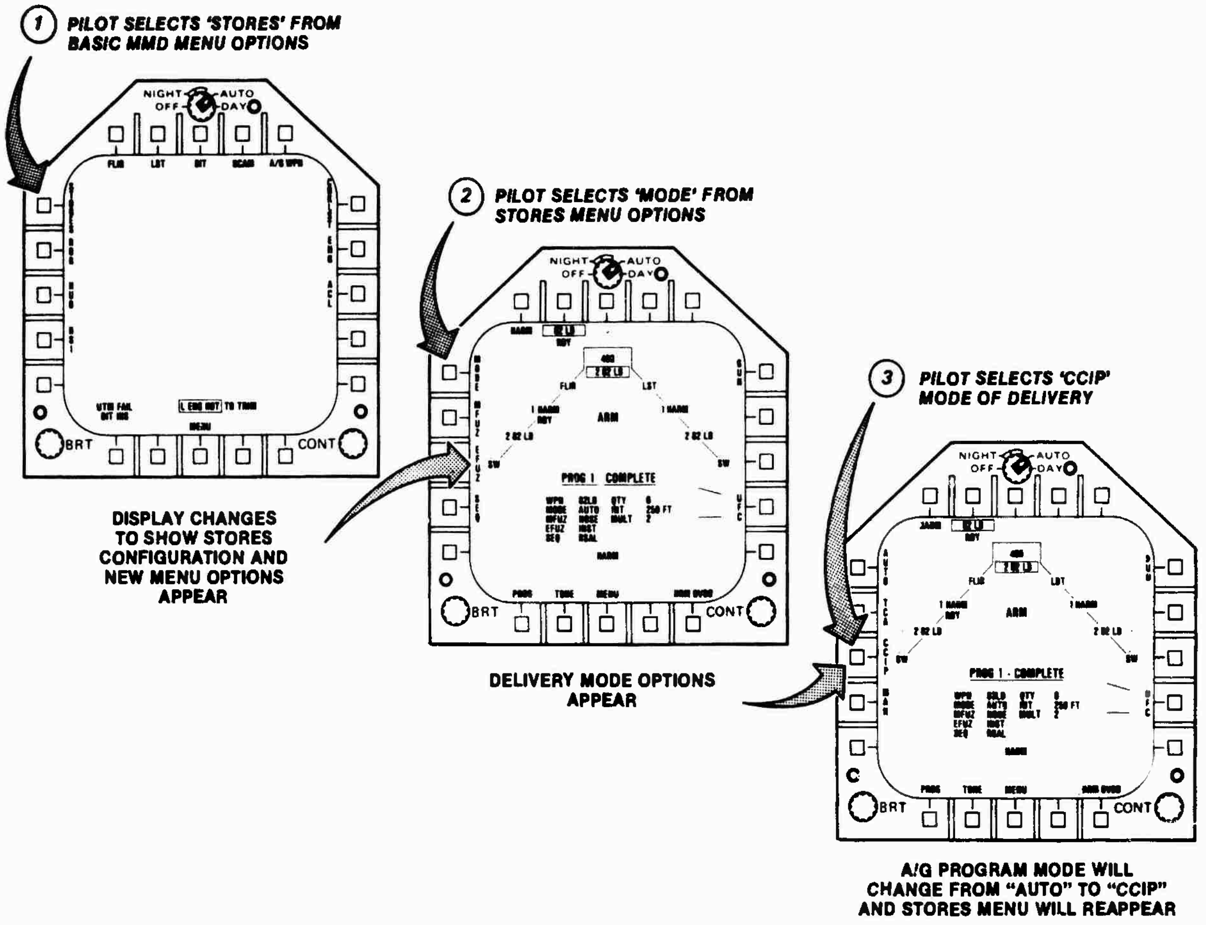


FIGURE 4
MENU CONCEPT

The Up-Front Control (UFC) panel provides computer aided head-up control of the two UHF/VHF radios, ILS, Data Link, TACAN, Beacon, ADF, IFF and auto-pilot modes. The panel is mounted on the front face of the HUD electronics unit within easy reach of either hand.

Radar/Attack Sensors - The principle sensor of the F/A-18 weapon system for both fighter and attack missions is the Hughes AN/APG-65 multimode radar. This radar provides better weapon delivery performance than the A-7 and surpasses the F-4 radar in the fighter role. The radar satisfies these performance objectives at half the weight and volume, with four times the reliability of the F-4J radar. Its versatility is illustrated by the air-to-air and air-to-surface modes which include;

Air-to-Air
- o Velocity Search
- o Range While Search
- o Track While Scan
- o Raid Assessment
- o Air Combat Maneuvering (ACM)
  - Boresight
  - HUD
  - Verticsl
  - Gun Acquisition
- o Special Short Range Track

Air-to-Surface
- o Real Beam Ground Map
- o Doppler Beam Sharpening (DBS)
- o Ground Moving Target Indication/Track
- o Fixed Target Track
- o Terrain Avoidance
- o Sea Surface Targeting
- o Air-to-Ground Ranging
- o Precision Velocity Update

The key to the radar's flexibility is its high speed programmable processors and large (256K) disc memory. Software programs for all the modes are stored on the disc memory. When a different mode is selected by the pilot during flight, the associated software program is transferred to the operating memories in the radar signal and data processors. The programmable processors combined with the large memory capacity will accommodate new radar modes and provide an adaptive ECCM capability well into the future.

In addition to the multimode radar, a Forward Looking Infrared Set (FLIR) and a Laser spot Tracker (LST) are employed for the light attack role. With these integrated attack sensors, the F/A-18 offers better navigation, target location, track capability and delivery accuracy than any existing fighter/attack system.

The FLIR has 3° and 12° fields of view and a field-of-regard which covers all nonshadowed aircraft regions other than a 30° cone at the tail of the aircraft. It has the capability both for self-tracking and being cued by the radar or navigation system.

The LST automatically searches out and tracks targets being illuminated by a forward controller or an airborne illuminator. Search patterns for the 8° FOV seeker include a ±20° azimuth scan and a HUD field-of-view scan.

A Strike Camera, installed in a rotary mount at the rear of the LST pod, is computer directed and photographs the target area as the aircraft egresses.

Stores Management - The stores management functions are handled by a digital processor and individual stores decoders located at the external store stations. This design approach, which uses a dedicated multiplex bus to pass information between the processor and the decoders, minimizes the traditional weight penalty resulting from large quantities of armament wires over long routing paths. Additionally, armament changes can ordinarily be accommodated by interface modifications in the decoders and software changes in the processor, eliminating the need for difficult wiring retrofits.

Flight Control - To provide good handling qualities throughout its wide range of flight conditions, including the demanding carrier landing phase, the F/A-18 incorporates a digital, quad-redundant control-by-wire flight control system. The Flight Control Electronics Set computes aircraft stability and handling qualities for each phase of flight. Its four channels of digital electronics and sensors assure "fail-operational" performance and are backed up by direct electrical and direct mechanical link modes. Integrated pilot assist (autopilot) modes include: heading select, heading, attitude, speed and barometric or radar altitude hold, traffic control and automatic carrier landing, approach power compensation, and vector and precision course direction combat modes.

CNI - Primary cockpit control of the CNI equipment is performed from the Up-Front Control Panel. Memory and software control for these functions resides in the programmable communication system control unit.

Voice communication is provided by the two new ARC-182 UHF/VHF - AM/FM transmitter-receivers. These are integrated with the KY-58 crypto computer for secure voice and with the direction finding set for navigational bearings. The intercom set provides for voice communication with ground maintenance personnel and the rear crewman of the two seat trainer, as well as providing preprogrammed voice messages for alerting the pilot of critical information.

Radio navigational systems include the AN/ARN-118 TACAN, AN/ARA-63 ILS, AN/APN-202 beacon, R-1623/APN receiver, AN/APN-194 radar altimeter and RT-1379/ASW two way data link.

TACAN range and bearing are used in the mission computer to compute steering to any selected waypoint or target, in addition to the TACAN station.

The data link provides airborne target designation, vectoring and handoff. Data link transfer of initial inertial alignment and waypoint insertion data, and guidance signals for automatic carrier landing are available from the aircraft carrier.

Self-identification is accomplished by the AN/APX-100 IFF Set with crypto capability provided by the KIT-1A/TSEC equipment.

Navigation - The AN/ASN-130 is the primary kinematic sensor in the F/A-18. Navigation performance during flight test was 0.6 nm/hr CEP. Its outputs include aircraft attitude, attitude rates, heading, velocity, acceleration, and latitude/longitude. These signals are integrated throughout the weapon system for accurate navigation, air-to-surface weapon delivery, radar velocity augmentation and lead computing gunnery. The air data system provides backup navigation and primary flight aids data for flight control scheduling and cockpit display. Navigation updates are available from TACAN, radar, FLIR and visual offset or overflight.

Electronic Warfare - The EW Suite consists of the new technology AN/ALR-67 Radar Warning Receiver currently in development by the Navy, an internal AN/ALQ-126 ECM Jammer, and the AN/ALE-39 dispenser for releasing chaff, IR flares and active RF devices.

Reliability and Maintainability - The most capable systems in the world are worth little if they fail too often and are time consuming to maintain.

Five basic strategies are employed to increase system reliability. These are to: standardize and reduce the number of equipments and components; design and manufacture reliability into each equipment; provide an aircraft environment less likely to cause equipment failure; test equipment to the actual operational mission environment, and operate the equipment only when necessary.

Resulting reliability characteristics include:

- A 5:1 reduction in control/display units
- Use of the INS for the lead computing sight functions
- Cool ECS air (40°F maximum) dried by a high pressure water separator for lower unit temperatures
- An automatic avionics ground cooling fan, with thermal interlock
- A reduction of avionics ground operation by functionally isolated electrical power circuits
- Derating of component temperature and power requirements, even below NASA space requirements
- Stringent parts selection and screening
- More efficient heat extraction designs
- Critical equipment tested to operational mission environment

Initial proof of the success of the reliability design was obtained in the 100 flight hour reliability demonstration flown in November 1981 at NATC, Patuxent River, Maryland, on the 11th F/A-18 Hornet. During this demonstration milestone, in which a variety of typical fighter/attack missions were flown, only three avionics failures occurred. The radar did not fail during this test. Mean flight hours between failures for the complete aircraft were 8.4, versus the specification guarantee of 3.7 hours.

Combining high reliability with the Hornet's new maintenance features make it the most supportable aircraft ever introduced to the fleet. The time and effort to correct a defective subsystem on the Hornet are significantly reduced by the high capability Built-In-Test (BIT) system and a tremendous improvement in box accessibility. 89% of the units are at chest height and none are hidden behind others. The comprehensive avionic BIT system is designed for failure detection to 98% and fault isolation to 99%. Cockpit control and display status on the left hand multifunction display, is available both in flight and on the ground. To enable the pilot to assess the ability to complete a mission, equipment operational readiness and backup mode information are automatically displayed.

The Maintenance Monitor Panel, located in the nose wheel well, has 142 avionic Weapon Replaceable Assembly discrepancy codes which cue the maintenance crew to the proper aircraft access door and to failed components. Additionally, there are 116 MMP discrepancy codes for engine and air-vehicle components and 12 servicing codes for hydraulics, fluids, structural overstress and tape recorder reload.

Other cost-reducing maintenance capabilities include the Maintenance Signal Data Recorder, which records engine data and airframe structural fatigue cycles on a readily removable tape cassette, and the Electronic Boresight Unit, which allows dialing in boresight compensation to the computers in place of traditional mechanical shimming.

THE KEY FEATURE FOR TODAY AND TOMORROW

The purpose of the F/A-18 weapons system is to minimize sorties per kill. This requires accurately and reliably delivering air-to-air and air-to-ground weapons on targets that must be detected, identified, acquired and tracked by the pilot using smart weapons and sensors. The key to modern avionics is computer technology; and the key to avionics computer technology in the F/A-18 is the integration of the data processing. The pilot, in addition to flying the aircraft, must monitor the instruments to ensure that the weapon system can accomplish its purpose. Every decision that could be safely removed from the pilot's tasks is performed by the highly integrated computational subsystem. This subsystem, as shown in Figure 5, consists of two mission computers and peripheral computers in sensor and display equipment. The airborne computational tasks are divided into two general categories, e.g., sensor-oriented computations and mission-oriented computations.

Sensor-oriented computations are those such as sensor coordinate transformations, platform management and signal processing, which are peculiar to a particular sensor or display. They are performed in sensor subsystem processors. Mission-oriented computations, such as weapon launch calculations, are related directly to performing the mission and depend on information from several avionics subsystems. Mission-oriented computations are performed in two mission computers.

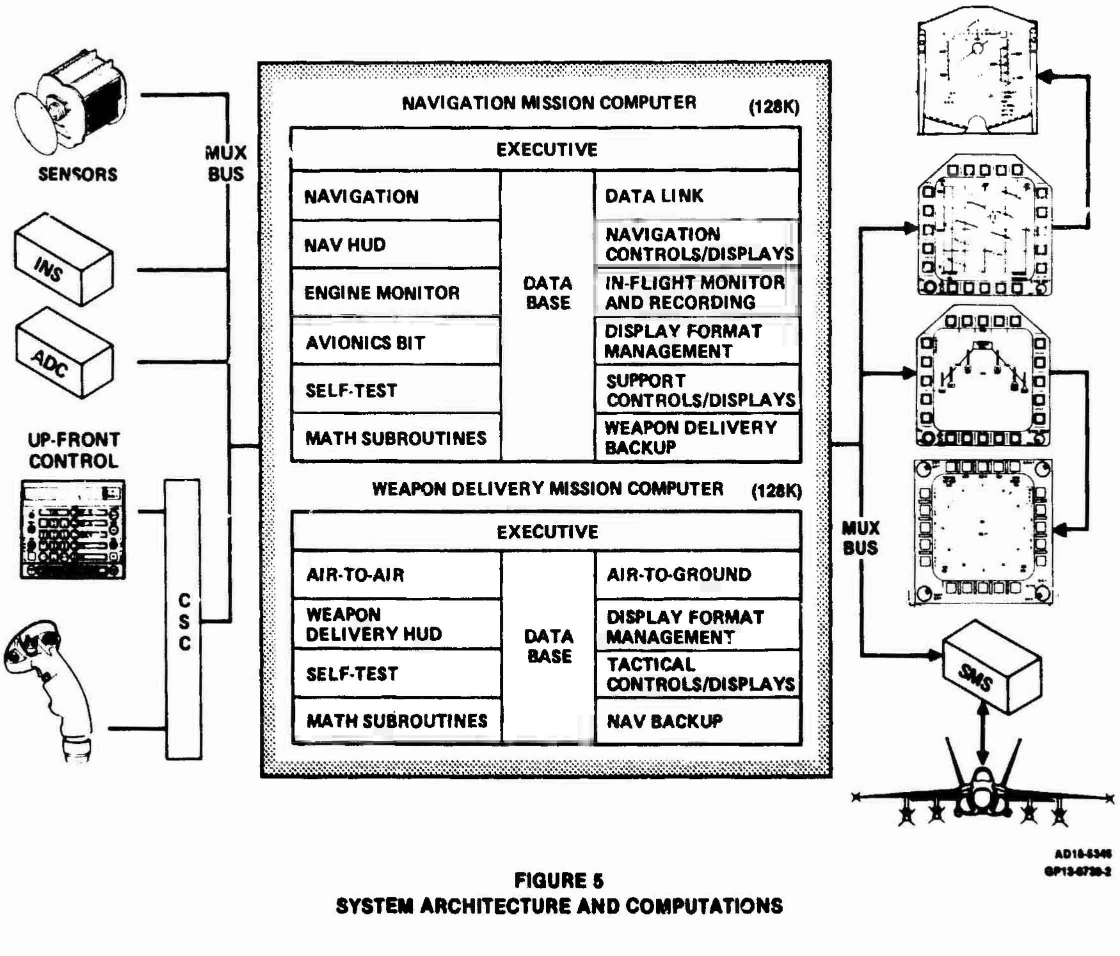


FIGURE 5
SYSTEM ARCHITECTURE AND COMPUTATIONS

The design approach provides functional modularity of the sensors and integration by the mission computers. Benefits offered by this architecture include a high degree of parallel processing capability, avoiding unnecessarily high speeds in any one processor; simplification of subsystem interfaces in quantity and data rates; easier design and development of the integrated avionic system in parallel with the subsystems; clear division of system/subsystem responsibility and effective use of engineering/manufacturing expertise; simplification of maintenance through functional modularity; and ease of growth.

Sensor-Oriented Processing - There are four major subsystem-embedded reprogrammable computers and a number of smaller subsystems with embedded microprocessors with read-only memories (ROM). Each sensor computer performs only those computations necessary for that sensor to perform its well-defined task. This includes all computations required to translate some measured physical parameter, such as air pressure, into useful information for the pilot, such as altitude, air speed, and Mach number. Once the information is computed, it is sent to the mission computer over the avionics multiplex bus. There it is used with information from other sensors to perform the mission-oriented computations as well as for display to the pilot.

Mission Computer Processing - The mission computer (MC) subsystem consists of two identical U.S. Navy Standard Airborne Computers designated AN/AYK-14. Although the hardware of the two computers is identical, their computer programs are different and are dedicated to specific processing tasks. The AN/AYK-14 is a high speed, general purpose digital computer specifically designed to meet the real-time requirements of an airborne weapon system, while retaining compatibility with existing higher order language support software. Each computer was originally delivered with a memory capacity of 64K 16 bit words, but this capability is being increased to 128K by inserting physically interchangeable double density memory modules. Each mission computer is dedicated to specific processing tasks by means of its stored program. One computer is assigned the navigation and support processing tasks and associated display management. The other computer is assigned the air-to-air and air-to-ground weapon delivery processing tasks and associated display management. Each computer has a small back-up software module for selected functions of the other computer. The navigation computer has a small weapon delivery back-up software module and the weapon delivery computer has a small navigation back-up software module. These back-up modules are executed only in the event the primary computer for these functions should fail.

F/A-18 Avionics Multiplex System - Digital data between the Mission Computers and the peripheral avionics components is transferred on the MC-controlled Avionics Multiplex system. The system consists of three multiplex channels. Each channel consists of two redundant 1 MHz MIL-STD-1553A data buses, each operated in a half-duplex fashion. All peripheral units on a single channel are connected to the transmission lines comprising that channel in parallel, party-line fashion, such that physical removal of a unit from the lines does not interrupt the continuity of the lines. All units on the same channel see all of the data on that pair of buses. However, on a given channel, data is transferred only between the MC and a single peripheral at a time. Each bus is independently routed through the aircraft to ensure reliable communication in the event of damage. Only one of the buses of each redundant pair is active at any one time. The MC selects which of the data buses is to be used for data transmission and initiates each data exchange over the selected bus. The mission computers include independent controllers for each of the multiplex channels permitting full use of the computer for processing tasks during input/output. Control of the multiplex system is transferred between the two MCs based on priority of need.

Integration Flexibility - The combination of central mission computers and distributed processing in the peripheral computers that comprise the various subsystems gives the F/A-18 a powerful integration flexibility. As shown in Figure 6, the individual sensors with their special processors are readily integrated via the multiplex lines and the central computer. The addition of new sensors is accomplished by adding the sensor and its dedicated processor to the multiplex bus and programming the mission computer to provide the required integration functions.

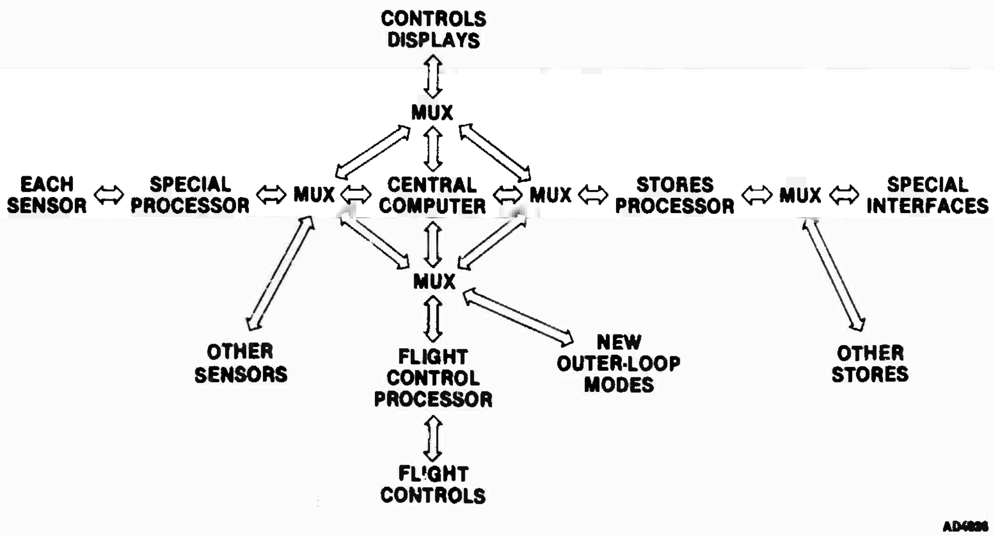


FIGURE 6
INTEGRATION FLEXIBILITY

ENHANCEMENTS UNDERWAY

The built-in flexibility of the F/A-18 avionics system permits a wide range of enhancements to be readily incorporated into the basic airplane.

ASPJ - The Airborne Self Protection Jammer is the newest countermeasure equipment being developed by the U.S. Navy for joint Navy and Air Force use. The ASPJ is a modular, software-controlled system that is electrically reprogrammable to enhance ASPJ's ability to counter the existing and future threats with minimal impact on cost. It provides more effective and sophisticated pulse and CW jamming of radar threats. As shown in Figure 7, installation and integration are especially easy on the F/A-18. Internal mounting, cooling, waveguide routing and antenna placement are already available, and no new equipment bay design is required.

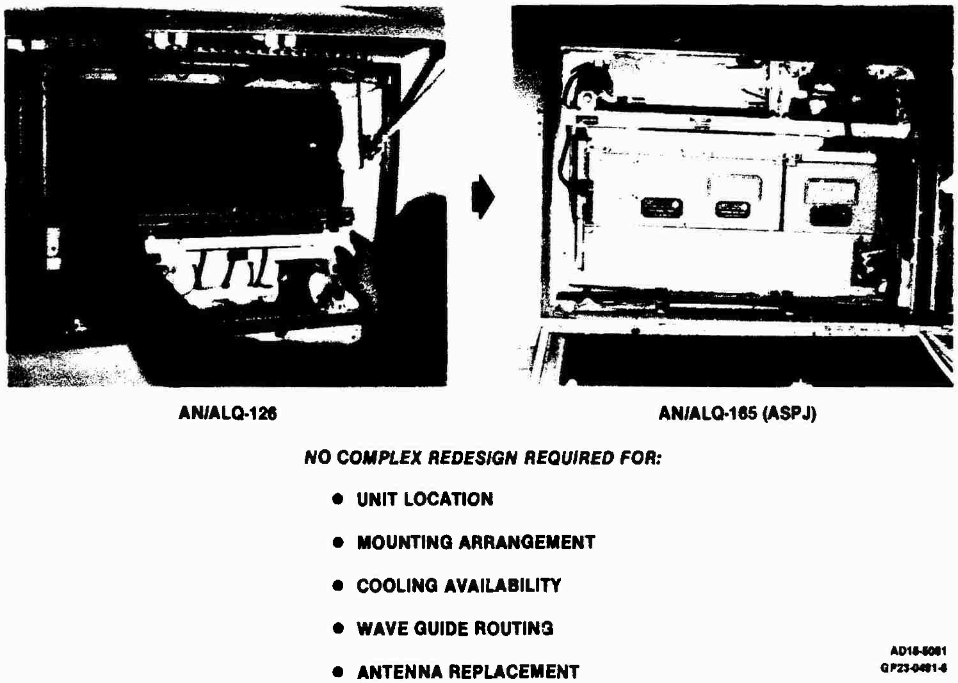


FIGURE 7
HORNET IS CONFIGURED FOR ADVANCED
INTERNAL ECM

JTIDS - The Joint Tactical Information Distribution System will provide secure, jam resistant, digital data and voice communication. This will significantly enhance combat control, surveillance, air traffic control and information management as well as provide an inherent precise location and identification capability. Current plans call for the Hornet to be the first USN airplane to receive JTIDS and 70% of the USN aviation terminals are scheduled for Hornets. Since JTIDS is a digital data link, its introduction into the digital Hornet is significantly simplified.

AMRAAM - The Advanced Medium Range Air-to-Air Missile development program is underway. Missile integration on the Hornet is facilitated by the existing multiplexed armament data bus, the current capability of the airplane to carry AIM-7F Sparrow missiles and current availability of complementary radar modes. Controls, displays, and launch and steering computations require only software changes for AMRAAM compatibility.

LTD/R - The laser target designator/ranger, which will be installed in reserved space in the Forward Looking Infrared (FLIR) Detecting Set, AN/AAS-38, provides a self-contained laser with autonomous designation and ranging capability. Inherent advantages are a more effective means of designating targets, decreased vulnerability of pilots and aircraft, increased mission flexibility and increased number of targets attacked. Vulnerability of pilots and aircraft is reduced because no need exists for coordination either with a less maneuverable designator aircraft or a more vulnerable ground designator. Increased mission flexibility results from autonomous designation since the attack aircraft has more freedom to choose approach and maneuver tactics over the target area without rendezvous-imposed constraints.

Improved Radar Resolution - The production radar Doppler Beam Sharpened (DBS) mapping capability is being expanded to extend the range of the existing 67:1 DBS mode by a factor of five. It is a measure of the inherent capacity of the radar that this change is accomplished entirely in software. This change is currently in flight test.

Tactical Reconnaissance - As the fighter/attack Hornet is being introduced to fleet service, the Naval Air Development Center and McDonnell Douglas are developing a third mission role capability for the Hornet: Tactical Reconnaissance. An engineering test bed demonstrator is scheduled to fly in early

1984, combining the Hornet's existing air vehicle performance, flight control, sensor, and cockpit display capabilities with traditional reconnaissance sensors. The RF/A-18 Engineering Test Bed will integrate tactical reconnaissance capabilities into the existing fighter/attack weapon system with minimal change in F/A-18 performance or capability.

This initial reconnaissance capability is achieved by temporary gun removal and substitution of a reconnaissance equipment pallet. A mix of sensors can be installed on this pallet to obtain frame, panoramic or infrared line scan imagery, depending on light, weather, overflight altitude, standoff range and the mission objective. These sensors can be operated automatically and are further augmented by the excellent imagery provided by the F/A-18's current production radar and forward looking infrared (FLIR) set. Near-real-time digital data is made available through the Hornet's current data link. As an aid to the pilot, a ground track hold mode will be added.

In addition to the Hornet's multimode radar real beam ground map, other air-to-surface modes are readily usable for reconnaissance missions. The radar detects and locks onto moving and fixed targets; detects ships using a sea search mode; generates a display for low altitude terrain avoidance; and displays Doppler beam sharpened (DBS) imagery that provides either a 19:1 or 67:1 azimuth resolution enhancement over real beam ground map. The extended range resolution improvement will provide resolution enhancement at longer ranges without hardware changes.

The AN/AAS-38 FLIR, developed for the attack Hornet, also is planned for use in reconnaissance missions. Its aimable high resolution infrared sensor, with a large field-of-regard, covers essentially the entire lower hemisphere.

Link 4, normally used for intercept control, can be used on reconnaissance missions to transmit target data including both position and identification messages.

The RF/A-18, shown in Figure 8, is capable of substantial growth to provide high resolution radar, long standoff operation and real time imaging data link.

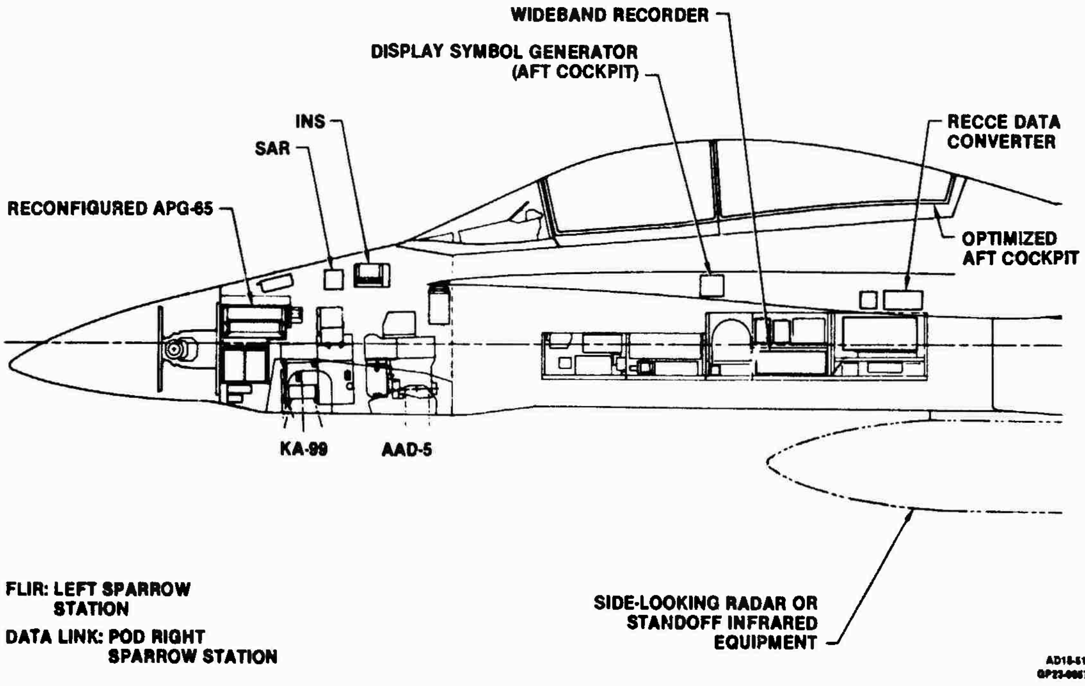


FIGURE 8
RECONNAISSANCE SENSOR AND EQUIPMENT ARRANGEMENT

Conversion to fighter or attack roles requires only the time it takes to rearm the aircraft. About eight hours are needed if it is desired to refit the gun.

Attack Enhancements - Modifications such as those illustrated in Figure 9 are being investigated for increasing the weapon system utility and effectiveness and increasing survivability. To expand the weapon system utility, day/night, low level navigation sensors are being evaluated. Communications and battle area awareness will be enhanced by JTIDS. Precision navigation systems, very high resolution radar and automatic target recognition technology will increase the probability of detecting and recognizing the targets. These sensors and new weapon delivery algorithms will permit manual or coupled maneuvering (non-wings level) attack day/night and in adverse weather with a high probability of target kill and aircraft survivability.

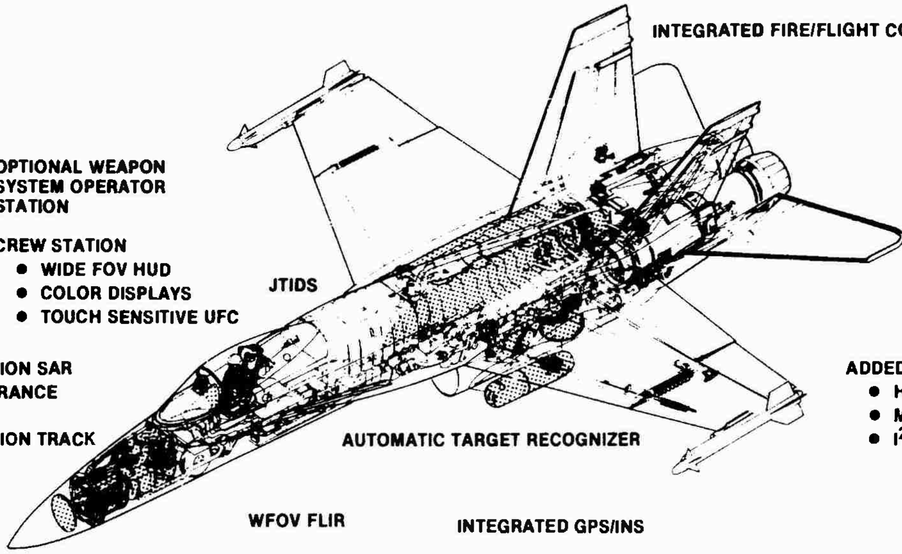
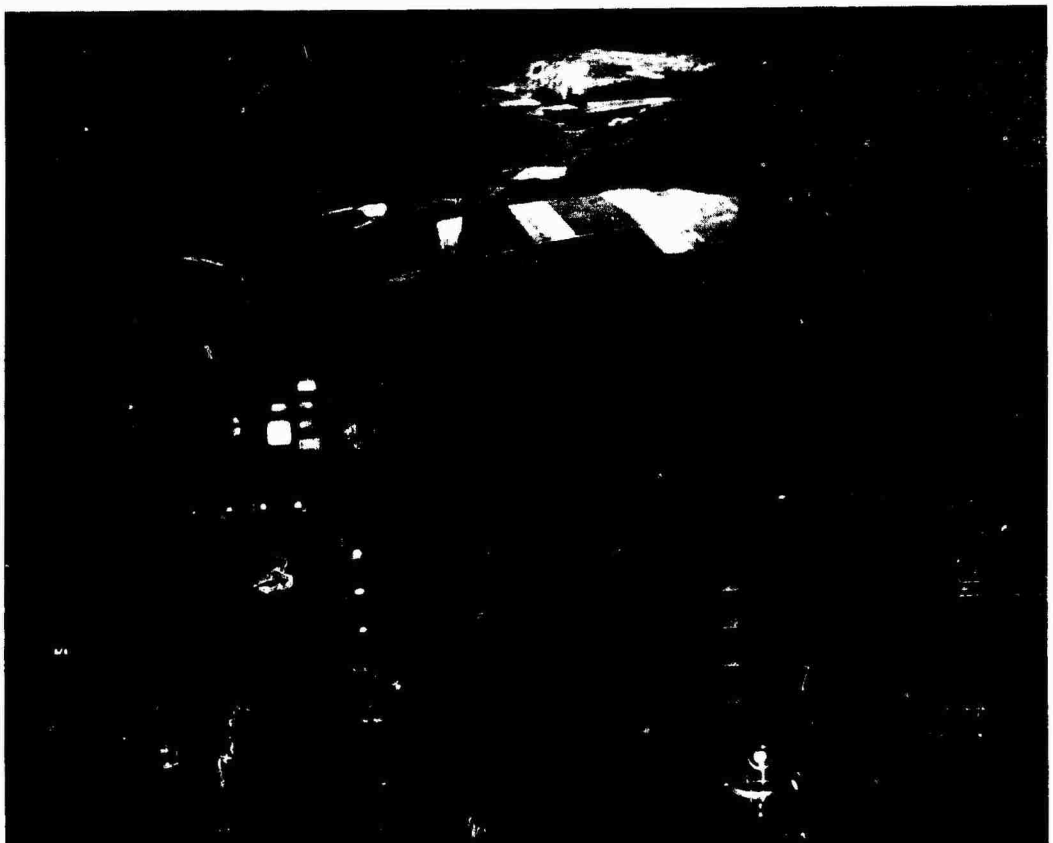


FIGURE 9
ATTACK ENHANCEMENTS

AD18-5351
GP33-0141-2

Cockpit enhancements will include additional integration of threat warning and ECCM features, installation of wide field-of-view raster HUD and color displays, and higher levels of automation. The wide field of view HUD, illustrated in Figure 10, provides data display and cueing information to the pilot while remaining head-up without cluttering the central flight presentations. Raster compatibility permits the display of WFOV FLIR imagery for low level navigation. To provide up front control capability while providing more flexible display area, interactive flat panel displays with raster capability will be pursued. The interactive flat panel provides the needed central display of threat warning data and provides a flexible control panel for management of sensors and missionized avionics



AD18-5352
GP33-0141-5

FIGURE 10
WIDE FIELD-OF-VIEW HEAD UP DISPLAY

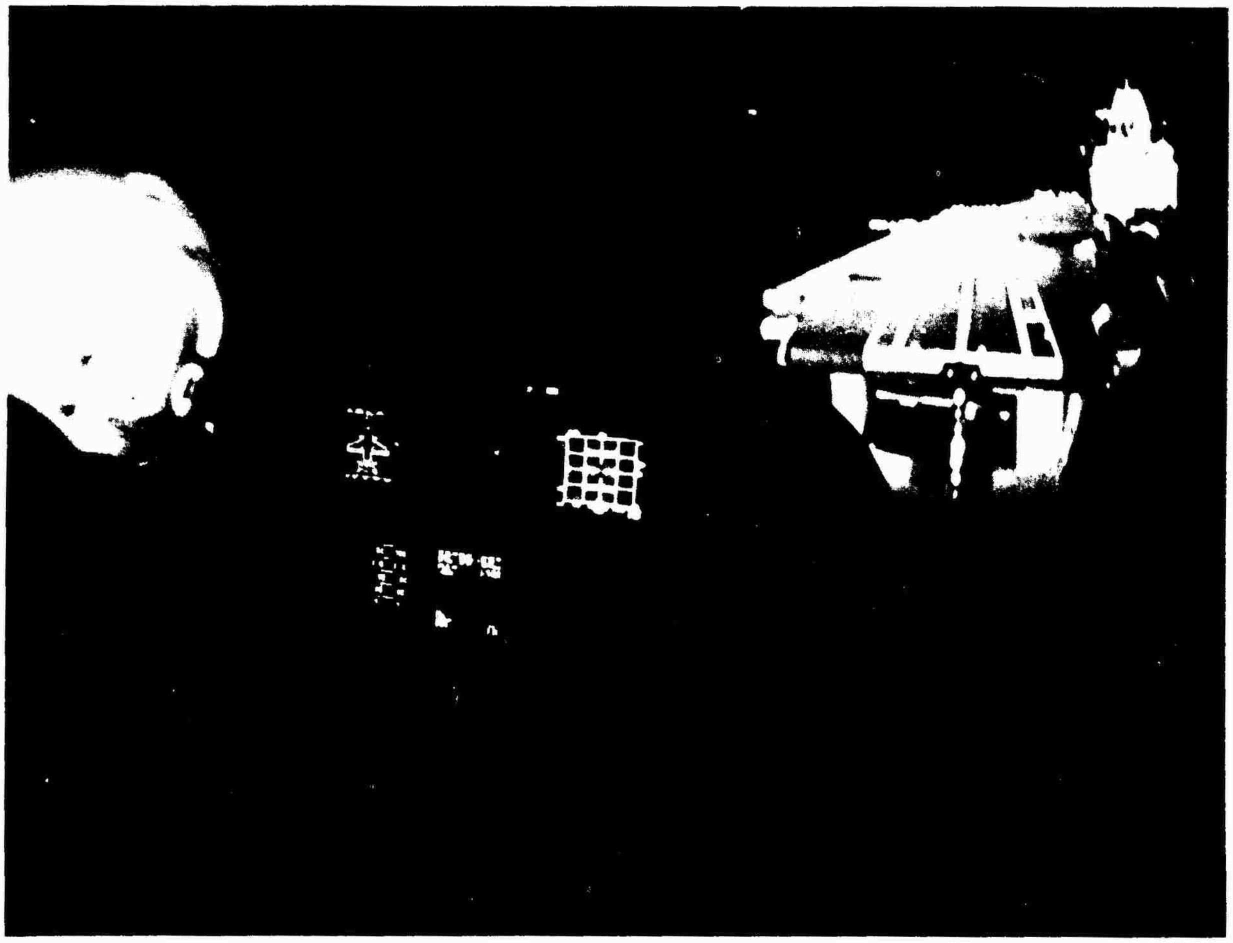
packages. The option for a dedicated weapons system operator station is also available to extend attack system capability into a more hostile environment. The weapon system operator station will have display formats independent of those selected in the front and will have a sensor display optimized in size for the high resolution sensors. Simultaneous operation of selected radar modes is planned, with the radar modified to provide two concurrent displays.

Stores Management Processor and Mission Computer software will be updated to [illegible] Maverick and mine capability.

SIMULATION

All of the enhancements described above are already being flown or evaluated by pilots in MCAIR's Manned Air Simulation facility. The facility permits system functional integration on a scale and with a fidelity not otherwise available. It is a unified laboratory complex oriented primarily toward, but not limited to, manned, real-time flight simulation. It is comprised of a dedicated computer complex, six crew-stations (five fixed base and one motion base), terrain maps, horizon displays, airborne target displays, and associated hardware. This facility offers a wide range of flexibility, emphasizing the goal of achieving efficient, low cost and accurate simulations of modern aircraft systems. The core of the flight simulation laboratory is a Control Data Corporation (CDC) CYBER 7600 digital computer. Active primary and secondary flight controls and active flight instruments are provided. "G" effects are provided by "G" suits, "G" cushions and blackout simulation. Sound cues of gun firing, missile launches, engine rpm, afterburner, speedbrake, skin noise, wind over canopy, flaps, landing gear, buffet, tire contact and runway rumble are provided. Radar, HUD's and other special displays and controls are provided as required. This highly integrated system provides central software control for any simulation problem. It is used to evaluate avionics systems, flight controls, cockpit arrangement and displays, fighter gun and missile effectiveness, and to develop new tactics for fighter aircraft.

MCAIR's simulation approach is to apply simulation techniques in all phases of weapons system (or subsystem) design from concept through deployment. The F/A-18 aircraft was totally simulated long before the first flight. MCAIR and customer pilot's "hands-on" experience of flying in the simulator, Figure 11, permits user inputs early in the design phase. The result is significantly lower development cost with substantially higher operational effectiveness and utilization than could be achieved by other development techniques.



AD18 5354
GP33-0141-3

FIGURE 11
FLIGHT SIMULATOR

CONCLUSION

The F/A-18, Figure 12, provides unique capability in its digital avionics and high degree of integration. When combined with the engineering resources of modern software and simulation facilities, the significant growth potential can be exploited. These programs are under way.

AD18-5353
GP33-0141-4

FIGURE 12
ADVANCED TECHNOLOGY TODAY AND TOMORROW

DISCUSSION

J.Mitchell, UK

Are you considering installation of NAVSTAR/GPS in the F-18?

Author's Reply

Yes. USN has been told how much it would cost. We are awaiting a decision.

R.Davies, Ca

(1) F-14 has recently introduced a Beyond Visual Range Daylight Visual TV Sight Unit. Why not on USN F-18?

(2) USMC traditionally want close attack aircraft close to their beachhead or FEBA. How do they achieve a quick response with the F-18 INS?

Author's Reply

(1) The US Navy has not identified a need for a beyond visual range daylight sight system in the F/A-18A.

(2) The F/A-18A INS, the AN/ASN-130, provides attitude heading reference (AHRS) data within 30 seconds of turn-on. The aircraft can fly all A/A and most A/G missions on AHRS data only. If the aircraft has not been moved since shutdown (stored heading) the INS will be fully aligned in 4 minutes. Otherwise, the full gyro compass alignment time is six minutes.

J.O.Vaillancourt, Ca

Is the FLIR the Ford Aerospace system? Is it in production to be procured by the USN?

Author's Reply

The AN/AAS-38 FLIR subsystem is built under contract to MCAIR by Ford Aerospace with Texas Instruments being the major subcontractor for common module IR components. The first production lot purchase order was placed May 1982 with the first production unit scheduled for delivery to the US Navy on 1 April 1984.

DEF STAN 00-18: A FAMILY OF COMPATIBLE DIGITAL INTERFACE STANDARDS

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SUMMARY

~~The~~ This paper discusses the results of work undertaken by the joint MOD(PE)/Industry Data Transmission Standards Committee (DTSC) in the formulation and promulgation of UK Defence Standard techniques for digital interfaces in aircraft systems.

Four data transmission standards prepared by the DTSC have now been published ~~by MOD~~ as parts of DEF STAN 00-18, and these are described. They constitute a compatible family of standards for avionic data transmission to meet the majority of current system requirements, and have served to focus both component and system development resources within the UK, to the benefit of both MOD and Industry. The paper touches on the associated Sub-committee activity within DTSC, and the guide to the use of the standards which has been published as Part 1 of the DEF STAN. It concludes with a discussion of future plans and new options for standardisation.

1 INTRODUCTION

There is an ever-present need for standardisation, particularly in the case of military equipment, where there is a prime aim to reduce development, acquisition and life-cycle costs and to improve interoperability. Rapid changes in technology, however, often conflict with this objective with the result that either the standards quickly become obsolescent or they suffer the accusation of stultifying technological progress.

One way around this problem is to look for standardisation initiatives at interfaces, both physical and conceptual, and in the airborne data transmission field at present near ideal conditions exist for standardisation. This is because overall data transmission requirements for current and near-future systems are reasonably static in terms of such things as bandwidth, iteration rates, and so on. There is also a genuine desire by all parties involved, suppliers and customers alike, to co-operate in finding acceptable technical solutions to the problem.

This paper, then, describes the formulation of the joint MOD(PE)/Industry Data Transmission Standards Committee (DTSC), and the co-operative efforts which have resulted in defining the requirements, producing and supporting the DEF STAN 00-18 series of standards, the vehicle for airborne data transmission standardisation.

2 THE DATA TRANSMISSION STANDARDS COMMITTEE (DTSC)

Within the UK, Industry and Government views on avionics systems research are established by the Joint Committee for Avionic Systems Research (JCASR). Industry is represented by the Electrical Engineering Association (EEA) in conjunction with the Society of British Aerospace Companies (SBAC), and the Government by MOD(PE), the Department of Industry and the Civil Aviation Authority.

In 1973, under the auspices of a then existing liaison group of JCASR, a Digital Interfaces Sub Group (DISG) was formed to specifically look at the requirements for airborne data transmission and recommend, where possible, the formulation of standards for digital interfaces, primarily external to equipment.

By 1977, a list of six classes of interface had been identified and draft recommendations had been produced. The classes were as follows:

single-source, single-sink
single-source, multi-sink
multi-source, multi-sink
duplex serial link
discrete signalling
byte-oriented point-to-point link.

The DISG, however, was a voluntary association of Industry, with no financial resources to undertake the detailed specification and drafting, and with no formal links to the MOD Directorate of Standardisation (D STAN). At this point the MOD Directorate of Air Navigation and Reconnaissance (DA Nav) and RAE Flight Systems Department took a joint initiative to establish a new body to take over the formulation of interface standards. It would be funded by MOD(PE) to provide adequate agency and secretarial support, and would be capable of producing draft standards to the requirements of D STAN as well as providing a dedicated test house capability for EMC trials.

Thus the DTSC was formed in 1978, under the chairmanship of DA Nav and with RAE acting as Technical Authority. It comprises a main committee together with a number of sub-committees or working groups, each dealing with a particular specialist area. Committee and working group membership is open to any organisation concerned with the design, development or construction of data transmission systems. ERA Technology Ltd are funded to act as the DTSC agency, providing the secretariat and technical support, including a dedicated EMC test facility.

Control is exercised by two steering committees, both chaired by MOD(PE). The first directs future policy and considers recommendations from the main committee for new standards, working groups etc. The second is a specialist group concerned with the formulation of the test methods to be used within the EMC facility.

The primary objective of the DTSC is to produce and promulgate defence standards for airborne data transmission interface systems. Other aspects of the DTSC terms of reference include:

(i) Examination of the data transmission requirements of future military aircraft. The organisation is continually reviewing the likely impact of new technology so as to be prepared for standardisation requirements and opportunities in future systems.

(ii) Consideration of the applicability of existing national and international standards. This is an important aspect since the adoption, where practical, of suitable existing standards avoids duplication of effort and enhances the possibility of NATO interoperability.

(iii) Assessment of the extent to which it is possible to implement standards to meet requirements. This aspect concerns the balance that any standards organisation must make between applications that appear regularly enough to benefit from standardisation, as opposed to those of a special nature where resources would not justify the creation of new standards.

(iv) Promotion and adoption of the standards nationally and internationally. Having produced standards it is important to advertise their existence and encourage their use so that the full benefits are obtained. It is for this reason that the DTSC reviews very carefully standards from other countries as well as promoting its own internationally through its formal liaison activities.

(v) Recommendations and provision of guidance in the application of the standards. Standards are by definition rather concise documents with little guidance on interpretation or practical implementation aspects. One of the main activities of DTSC has been the production of guides to help system and component designers, project managers etc understand and use the standards correctly.

As already mentioned, liaison with other national and international standardisation bodies is a very important aspect of DTSC activities, and either direct representation or regular correspondence is maintained with a number of bodies in order to expedite the exchange of information. Some of the bodies currently included are USAF, ASCC WP 50, NATOS MAS (AVSWP), SAE A-2K/AE-9, DELSC, BSI, EUROCAE, ARINC, IBA.

It was also stated earlier that the DTSC operates in a number of working groups. To date, four of these working groups have produced standards for publication in the DEF STAN 00-18 series, together with supporting guidance information. The DEF STAN will now be described before discussing the associated working group activities.

3 DEF STAN 00-18

All standards produced by DTSC have been published as individual parts in the DEF STAN 00-18 series, which has been allocated to avionic data transmission. This has provided a compact format where all the standards are related together using common terminology and layout. Part 1 contains all the guides which have been written as companions to the individual standards, which appear in parts 2-5.

3.1 Multiplex data bus standard

In 1977, MIL STD 1553A was recommended by the then DISG as being suitable for UK avionic applications. By the time DTSC was formed, firm national support had been established for adoption of the new 'B' version which was under consideration in the US, and in the formulation of which RAE was involved.

DTSC thus had a firm mandate to incorporate 1553B within the 00-18 series, and the Multiplex Data Bus Working Group was set up to progress it. The wording and format of the US document does not conform with the drafting rules laid down by DEF STAN, and it was also considered necessary to 'anglicise' some of the phraseology to improve clarity.

The work was undertaken to re-draft MIL STD 1553B into the DEF STAN format, and a firm policy decision was taken that the two documents must remain technically identical, to preserve compatibility. The Standard was published as DEF STAN 00-18 (Part 2) in April 1980 . The main differences from 1553B are in the clause numbering system, the use of metric units, and some phraseology. All diagrams are similar, but the Appendix from 1553B, dealing with redundancy, multiplex selection criteria and reliability aspects, has been omitted from Part 2 and included in the Part 1 Guide (discussed in section 3.5).

The Working Group has been responsible for preparation and maintenance of this section of the Guide, and continues to co-ordinate recommendations for updates. Through its liaison with SAE and USAF in particular, the Working Group continues to clarify points of contention or interpretation.

3.2 Single source, Single/multiple Sink (SSSMS) interface standard

This class of interface can find widespread application in simple systems, and was identified by DISG as a standardisation objective. DTSC concluded that whereas Part 2 (1553B) could be employed for such applications there was still a case for defining the simpler standard, since the overheads in the interface circuitry and software for handling the command/response protocols, which are not required for the SSSMS application, might be a deterrent to its use. The lack of a suitable simpler standard may then give rise to the type of proliferation which DTSC was trying to limit.

The SSSMS Working Group was, therefore, established to define and produce such a standard. Several existing methods and systems were reviewed, such as the Panavia 64 kbit/s system used in Tornado, ARINC 453 and 429, as well as STANAG 4153 and 4156. All were rejected, however, in favour of a system derived from Part 2 (1553B) using its resilient electrical features, which would ensure good electromagnetic compatibility. Furthermore, transmitter/receiver hardware, transformers, bus couplers and cable were specified to be identical to those for Part 2 (1553B) systems.

The protocol was deliberately kept simple, just enabling the transmission of data words or data/tag word pairs where the tag word can act as an identifier or qualifier, as in ARINC 429 systems.

Numerous single-source requirements can be met by this simple system, which was published as DEF STAN 00-18 (Part 3) in January 1981. A guide to the use of the Standard is included in Part 1.

3.3 Discrete signal interfaces standard

Discretes have traditionally been considered to be simple, low level interfaces, not worthy of particular attention, especially for standardisation. Analysis of recent aircraft systems, however, has shown a substantial increase in the number and types of essentially similar but different discrete types, the implications of which are interface and electromagnetic incompatibility, increased volume and mass and, of course, higher costs.

Thus, the Discretes Working Group was established to investigate the problem of reducing the proliferation to the minimum necessary set which could be incorporated into a standard. Through the work of the Group, the main functional requirements for discretes in avionics systems were isolated, and three categories of discrete were identified as candidates for standardisation. Within each of these categories a single interface was then defined to cover the majority of applications.

The three categories are as follows:

(a) Time-critical signalling

These discretes signal time-critical events, such as weapon release, audio blanking, event marking etc. The specified time-critical discrete employs balanced, differential signalling directly coupled using the same cable specification as Part 2 (1553B) systems, thus ensuring commonality. The link itself can handle a pulse repetition frequency up to 100 kHz.

(b) Non-time-critical signalling

These discretes signal non-time-critical conditions, such as status flags, mode indications, secondary alarms etc. The specified non-time-critical discrete employs single wire transmission, with the aircraft ground used as the signal return. The transmitting switch element can be either electromechanical or solid state, and the receiving element is a simple comparator with defined threshold and hysteresis characteristics.

(c) Low power switching

These discretes provide power with the signal for driving lamps, relays etc. The specified low power discrete defines an electromechanical or solid state switch from a load (lamp or relay) to the aircraft 28 V supply. Switching currents of up to 0.2 A are handled, and specifications are laid down for such parameters as rise and fall times, on-state voltage drop, off-state leakage and inductive load protection.

These three discrete specifications have been incorporated into DEF STAN 00-18 (Part 4) which was published in May 1981. The standard has been particularly successful at rationalising the large number of discrete options, and extensive EMC testing has been undertaken both at RAE and ERA Technology. The existence of the standard has also encouraged the development of suitable monolithic interface circuits, through the careful choice of electrical and physical parameters.

UK has submitted this standard for consideration by both NATO and ASCC.

3.4 Fibre optic transmission standard

The fibre optic transmission standard proved to be the most difficult to define, since the pace of technological change has precluded any attempt to standardise at this time on emitter/detector types, modulation techniques or connector types. However, the production of a standard was considered desirable in order to stimulate and focus the attention of industry on the special problems encountered in the avionics environment.

Thus the Fibre Optics Working Group was formed to consider the best way of approaching the standardisation of optical data transmission. It was decided that a structured format would be employed which was capable of being updated and expanded as the technology matures.

The standard was published as DEF STAN 00-18 (Part 5) in May 1981, and comprises six sections dealing with different aspects, as follows:

(i) Section A provides an introduction, a definition of terms used throughout the document and a section dealing with the purpose and limitations of the Standard.

(ii) Section B deals with general requirements such as the test and operating conditions, optical/electrical interface descriptions and the LRU/Harness considerations. At present three optical cable diameters are specified (100, 250 and 800 μ), although this is likely to be revised in the near future; in particular, 250 μ is likely to be changed to 200 μ.

(iii) Section C defines a 1 Mbit/s single-source transmission system where the performance is characterised in terms of rise/fall times, pulse and space widths. No constraint is placed on the number of sinks.

(iv) Section D defines a 10 Mbit/s single source system which is characterised in the same way as the 1 Mbit/s system.

(v) Section E defines the general requirements for an optical stub on the Part 2 (1553B) multiplex data bus and shows what configurations might be used in practice.

(vi) Section F defines the use of either the 1 Mbit/s or 10 Mbit/s data systems for fibre optic discrete interfaces, specifying the transmission rise times and propagation delay so as to retain compatibility with its electrical counterparts of Part 4.

Although the fibre optic standard requires further development, its existence has stimulated discussion and comment, and it has promoted fibre optic technology development. Fibre optics can now be considered as a realistic alternative to the use of electrical transmission media for avionic systems. DEF STAN 00-18 (Part 5) is under consideration by both NATO and ASCC.

3.5 Guide to DEF STAN 00-18

The complex nature of aircraft data systems has revealed the need for user guides to the standards in order to assist project managers, equipment and component suppliers, aircraft constructors and system designers.

The information contained should present detail on the background, scope and purpose of the standards as well as the results of practical implementation, so it is important that the information is regularly updated to include the latest experience.

This has been recognized during the development of DEF STAN 00-18, where the whole of Part 1 has been allocated to the guides which are the companions to the standards in Parts 2-5. Part 1 is divided into a number of sections.

Section 1 is a general introduction which is intended to provide the user with a rapid overview of the choice of standards available together with a brief description of their capabilities and applications. Section 2 is devoted to a detailed appraisal of the multiplex data bus standard, and includes material from the USAF Multiplex Handbook as well as UK experience. Of particular interest are Chapter 3 on preferred remote terminal responses and Chapter 11 on testing.

Section 3 provides a similar breakdown for the single source, single/multi sink data transmission system, and Sections 4 and 5 deal with the discrete and fibre optic standards, respectively.

4 OTHER DTSC ACTIVITIES

In addition to the working groups set up for the development of the standards detailed above, there has been, and continues to be, working group activity in other areas. Some of these are now discussed.

4.1 Preferred Components Working Group

This Group, which was discontinued in 1981, was intended to review the components requirements for engineering any of the standards in the DEF STAN 00-18 family. It concentrated mainly on the Part 2 (1553B) requirements, looking at the availability of transformers, connectors and cables, and was responsible for highlighting, for example, the need for improved specification bus coupling transformers. The Group's activities, however, were made largely redundant as more and more suppliers offered components that met the required specifications, and the Group was wound up.

4.2 Terminal Testing Working Group

One major problem in using the Part 2 (1553B) standard was considered to be the interpretation of many of the clauses concerning the operation of the communications protocol. It was felt that this could result in remote terminal designers producing interfaces that were incompatible for certain functions.

In order to alleviate this problem, the Terminal Testing Working Group was formed and tasked with the development of a universal production-type test plan, the contents of which would represent an agreed UK test philosophy and interpretation of the standard. This would then assure a reasonable first-order compatibility between terminals designed and manufactured in the UK, and would form the basis of an agreed acceptance procedure to be used by prime contractors for all Part 2 (1553B) interfaces from whatever source.

The outcome to date has been the first issue of the test plan, incorporated in Part 1, as discussed in section 3.5 above, together with a list of preferred terminal responses to commands that are illegal or illogical, and which, as such, are not specified in the standard.

4.3 Video Working Group

This is the newest of the DTSC working groups and was established in 1981 to consider the source, sink, distribution and line standards for avionic video systems. It is the first standardisation area to come under DTSC consideration which is non-digital in nature.

To date, most emphasis has been placed on the examination of line standards, and a draft UK standard has been developed which is compatible with the recommendations of NATO STANAG 3350. This has rationalised the large number of available line standards down to three, known as Class A (875 lines), Class B (625 lines) and Class C (525 lines). These are characterised in terms of all the aspects controlling the tolerance and levels of the baseband video waveform. The standard will be published in the near future as DEF STAN 00-18 (Part 6).

5 FUTURE DTSC ACTIVITIES

Future plans for DTSC activities include the continued support of DEF STAN 00-18, with a periodic review of the standards and their guides. Where appropriate, revised documents will be issued.

Principally, however, near and longer term standardisation objectives will continue to be formulated which will take account of advances in technology and development of system requirements. Several new areas are currently under consideration, as detailed below.

5.1 Video distribution

The use of video in modern avionic systems is increasing as more and more sources of video from remote sensors and waveform generators are required to be interfaced with the display systems for navigation and weapon aiming. This has highlighted the need to produce uniform requirements for such aspects as source and sink interfaces and distribution characteristics in addition to the line standard work mentioned in section 4.3.

Work being undertaken on the definition of source and sink interfaces will result in electrical specification for both balanced and unbalanced systems, in terms of impedances, voltage levels, rise times and circuit protection requirements, together with the definition of such transmission characteristics as bandwidth, crosstalk, signal/noise ratio and gain.

The resulting standard will, thus, include all aspects of the video system from generation to display. Longer term objectives will include a review of colour and digitally encoded video requirements.

5.2 Fibre optics multiplexing

Fibre optic technology already plays an important role in aircraft data transmission because of its superior EMC and isolation characteristics and the resulting potential wide bandwidth. The achievement of DEF STAN 00-18 (Part 5) has already been discussed, but the only multiplex application so far addressed has been the development of fibre optic stubbing techniques for electrical busses.

A near term objective will be the replacement of the complete electrical bus with a fibre optic solution, and DTSC has been in contact with SAE A2-K (AE9-C) on the potential MIL STD 1773. Further into the future, fibre optics is a strong candidate as the medium for video distribution and will probably be essential for any form of high speed bus application.

5.3 High speed multiplex bus

Future generation avionic systems will embody processing capability far in excess of current systems through the use of new technologies such as VLSI. There will almost certainly be a requirement for a high speed data-passing bus, probably in excess of 20 Mbit/s.

The development of such systems is still in the research phase, and DTSC has not considered the field mature enough yet for standardisation initiatives. A careful watching brief is maintained on developments in UK and elsewhere, and it is hoped to co-operate in the work of the High Speed Bus Sub-committee (AE9-B) of SAE in USA.

5.4 Multiplex data bus word standardisation

As MIL STD 1553B and equivalent data busses are finding widespread application throughout the aerospace industry, a natural leaning is towards the standardisation of word and message formats transmitted on the bus. This can improve compatibility between transmitting and receiving subsystems as well as allowing form, fit and function (F^3) objectives to be met.

Currently, the major activity in this area has been concentrated in a task group of the SAE AE9-A Committee, from which recommendations are emerging. DTSC is contributing to this exercise through the auspices of the NATO MAS AVSWP, and a UK version will probably be drafted as an advisory part of the DEF STAN 00-18 (Part 1) guide.

6 CONCLUSIONS

During the four years of its existence, DTSC has demonstrated the major benefits of a co-ordinated national effort towards the standardisation of aircraft data transmission systems. The value of joint Government and Industry participation has been immense, as both parties, manufacturer and customer alike, have co-operated in the development of standards. This has resulted in their immediate acceptance when required for use.

Four published and one draft standard have so far been produced which, together with the guides, represent a significant investment in time and effort. The result is a mature, compatible family of standards backed up by a large test and evaluation programme. This provides the UK with a good capability for our own aircraft system designs, together with the necessary experience to participate fully in the various international standardisation activities.

Techniques for Interbus Communication in a multibus Avionic System

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SUMMARY.

While studying the design of Total Aircraft Systems using MIL-STD-1553 Data Buses the need for interbus communication protocols in multibus architectures was established. Two types of interbus communication were identified as necessary: Cyclic message transfers and Acyclic message transfers. Cyclic messages are handled by assigning specific subaddresses in the Bus Controller Remote Terminals which receive and pass on these messages to the appropriate destination on a cyclic basis as preprogrammed in the relevant Bus Controllers. Acyclic messages are handled by a special protocol based on the use of the Service Request Bit in the status word, the Transmit Vector Word Mode Code, a specially formulated Vector Word, special Data Words which are used as Interbus Transmit and Interbus Receive Command Words, together with the use of reserved subaddresses, one for each bus on the network. This protocol is explained in detail together with the measures taken in the Subsystem to Remote Terminal Interface to ensure orderly transmission of data and effective error recovery with lost or corrupt messages.

1. INTRODUCTION.

British Aerospace Brough has been working on the design of Total Aircraft Systems using MIL-STD-1553 Data buses for some four years. During the last two years this effort has largely been concentrated on the design and construction of an Avionic Systems Demonstrator Rig (A.S.D.R.) funded by the Ministry of Defence.

The number of devices which have to be attached to the data bus in an aircraft system with distributed processing forces the adoption of a multibus architecture. (fig.5)

MIL-STD-1553 does not provide any explicit features for the handling of interbus message transfers. A problem which had to be solved for this multibus system was the specification of a set of techniques and protocols which allowed a range of interbus message transfers based on the MIL-STD-1553 building bricks.

These protocols had to cope with a number of possible Bus Network configurations.

i. A star configuration where one bus is a master and all the other buses are attached directly to this bus. (fig.1)

ii. A chain configuration where the buses form a linear network. (fig.2)

iii. Combinations of i. and ii. effectively giving a tree configuration. (fig.3)

A general requirement was made that the techniques and protocols devised should be able to cope with any of these types of bus network.

The architecture designed for the A.S.D.R. is a three bus system comprising an Avionics Bus, a General Services or Utilities Bus and a Stores Management Bus. These buses are interconnected by having Remote Terminals at the back of the General Services and Stores Management Bus Controllers attached to the Avionics Bus. See fig. (4).

The message types which had to be provided for the A.S.D.R. were :-

Bus Controller to Remote Terminal and Remote Terminal to Bus Controller where the Bus Controller and Remote Terminal were on separate buses.

Remote Terminal to Remote Terminal where the two Remote Terminals were on separate buses.

All these types of message transfer had to be organised for both Cyclic and Acyclic transfers. It was considered unneccesary to have Interbus Broadcast messages and so explicit protocols for this were not devised although the acyclic protocols would permit this type of transfer.

2. CYCLIC DATA TRANSFER.

Cyclic messages are the simplest to organise and can be done in two possible ways dependent on the number of messages that need to use this technique. If the number of messages to be transferred is small (less than 20) then a separate subaddress can be assigned to each message and the relevant Bus Controllers programmed to transfer the messages to and from the correct sources and destinations at the desired rates.

For example:-

If it is required to send a message of 10 data words from the Fuel Management System subaddress 6 on the General Services Bus to the Display System subaddress 3 on the Avionics Bus the following sequence of events must take place.

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For example:-

If it is required to send a message of 10 data words from the Fuel Management System subaddress 6 on the General Services Bus to the Display System subaddress 3 on the Avionics Bus the following sequence of events must take place.

The General Services Bus Controller as part of its normal cyclic message transfer sequence sends the command word to the Fuel Management System to transmit 10 data words from subaddress 6. The General Services Bus Controller receives these data words and transfers them into subaddress 15 of its Remote Terminal on the Avionics Bus. (We have arbitrarily chosen subaddress 15 for this specific message). At subaddress 15 these data words overwrite the previous contents thus ensuring that the data is always fresh. The Avionic Bus Controller as part of its cyclic message transfer sequence sends the commandwords to the Display System to receive 10 data words at subaddress 3 and to the General Services Bus Controller Remote Terminal to transmit 10 data words from subaddress 15. These data words are transmitted and received and the process is complete. Because these messages are cyclic error recovery is simplified, either the normal repeats of messages upon error detection by the relevant bus controllers ensures that the message gets through, or we accept that a new message is following in a few milliseconds. Error recovery beyond this strategy is very complex and is performed by the Executive Function of the Bus Controller, the discussion of which is outside the scope of this paper.

If the number of messages to be transfered is large then we can adopt the same general strategy but we now make the first data word in each package a header word which uniquely identifies the package of data.

The messages are transferred as before but now we can send several different messages to the same subaddress, the receiving system decodes the header word and copies the rest of the message out of the subaddress it was received at into a safe area within the subsystem.

When using this header technique in order to prevent overwriting of messages within the Bus Controller subaddresses we must queue the transfers from receive subaddress to transmit subaddress and force the communicating buses to run in synchronism on a minor cyclic basis so that the queues are emptied every minor cycle. Error recovery becomes more difficult because only a very limited amount of time can be allocated to retries if the buses are not to get too far out of sync so that the queues fill up and messages are lost.

3. ACYCLIC DATA TRANSFER.

The technique devised for the transfer of acyclic messages is most easily explained by going through examples.

Let us suppose that the Display System (RT 12) on the Avionics Bus needs to receive at subaddress 16 a package of 10 words of acyclic diagnostic data from the Fuel Management System (RT 7) on the General Services Bus. This package is available at subaddress 12 of the Fuel Management System and so the Display System formulates two special data words. One is an Interbus Transmit Word which is used to form the Command Word on the General Services Bus to cause the Fuel Management Unit to transmit 10 data words from subaddress 12. The other is an Interbus Receive Word which is used to form the Command Word on the Avionics Bus to cause the Display System to receive 10 data words at subaddress 16.

The Interbus Transmit Word is made up as follows :-

bits 0 - 4	contain a special Executive code to identify the bus to which the data is to return.
The codes are	11100 - for the General Services Bus
	11110 - for the Stores Management Bus
	11111 - for the Avionics Bus
bits 5 - 9	contain the subaddress from which the data is to be transmitted.
bit 10	is always set to a one.
bits 11 -15	contain the Remote Terminal address from which the data is to originate.
so for this example	it will be :-
	0011110110011111
	3 D 9 F Hex

The Interbus Receive Word is made up as follows :-

bits 0 - 4	contain the word count field. This specifies the number of actual data words to be sent.
bits 5 - 9	contain the subaddress field at which the data is to be received in the requesting subsystem.
bit 10	is always set to a zero.
bits 11 - 15	contain the Remote Terminal address at which the data is to be received.

so for this example it will be :-

0110001000001010

6 2 0 A   Hex

These two words are placed in subaddress 29 by the Displays System and then a special Vector Word is created which is formatted as follows:-

bits 0 - 4	contain the Word Count of the desired message. (That is two; the Interbus Transmit and Receive Words).
bits 5 - 9	contain the subaddress of the Remote Terminal with which communication is desired. If communication is desired with the Executive Function of the Bus Controller or with a Remote Terminal on another bus then this field contains a code word to be interpreted by the Executive Function. (see bits 11 - 15.)
bit 10	indicates whether the Remote Terminal specified by the RT address field bits 11 - 15 should transmit or receive, a one indicating transmit.
bits 11 - 15	contain the Remote Terminal address field with which communication is desired. If this field is set to all zeros then the desired communication is interpreted as a special code for the Executive. A Remote Terminal address field of all ones is interpreted as a request to broadcast.

The relevant special Executive codes are as follows:

11100	indicates that the Remote Terminal generating the Vector Word would like to communicate with a Remote Terminal on the General Services Bus.
11110	indicates that the Remote Terminal generating the Vector Word would like to communicate with a Remote Terminal on the Stores Management Bus.
11111	indicates that the Remote Terminal generating the Vector Word would Like to communicate with a Remote Terminal on the Avionics Bus.

and so will be for this example :-

0000001110000010

0 3 8 2   Hex

This Vector Word is loaded into the Remote Terminal and then the Service Request bit is set in the Status Word.

The Bus Controller detects the Service Request and sends a Transmit Vector Word Mode Code to the Displays. The Displays System responds with the Vector Word and is decoded by the Bus Controller which then requests the Displays to transmit two data words from subaddress 29 (the Interbus Transmit and Receive Words). The Avionics Bus Controller remembering the request in the Vector Word for interbus communication with the General Services Bus causes these two data words to be received by the Avionics Bus Remote Terminal on the General Services Bus Controller (RT 11) at subaddress 24.

Four subaddresses are reserved in each bus controller for interbus acyclic communications:-

SA 24 is for the General Services Bus

SA 25 is for the moment spare

SA 26 is for the Stores Management Bus

SA 27 is for the Avionics Bus

Because the two data words were sent to subaddress 24 then the General Services Bus Controller interprets the words as intended for it and decodes the first data word (the Interbus Transmit Word). Since bit 10 is a one it knows that this is an Interbus Transmit Word and decodes it as follows:-

The field of bits 0 - 4 is saved by the General Services Bus Controller remembering that it decodes to the Avionics Bus. The field of bits 0 - 4 in the second data word (Interbus Receive Word) is then copied into the field of bits 0 - 4 in the Interbus Transmit Word. The Interbus Transmit Word is then sent on the general services bus as a command word to the Fuel Management Unit to transmit 10 data words from subaddress 12.

These data words are received by the General Services Bus Controller which adds them to the Interbus Receive Word to make a package of 11 data words which it makes available at subaddress 29 it then sets up a Vector Word to request the Avionics Bus Controller to receive 11 data words (Interbus Receive Word + 10 data words).

This Vector Word is made up as follows :-

bits 0 - 4	01011	the word count (11).
bits 5 - 9	11111	indicates a transfer to the Avionics Bus saved from bits 0 - 4 of the Interbus Transmit Word.
bit 10	0	indicates receive.
bits 11-15	00000	indicates a special executive code.

So we have:- 0000001111101011

0 3 E B Hex

The General Services Bus Controller Remote Terminal then sets its Service Request bit in the Status Word.

The Avionic Bus Controller sees the Service Request bit set and requests a Vector Word which when decoded asks it to receive 11 data words from the General Services Bus Controller Remote Terminal subaddress 29 (subaddress 29 is used by convention with Vector Words).

The Avionics Bus Controller receives these data words which it knows from the Vector Word are a message for the Avionics Bus. It decodes bit 10 of the first data word and because it is a zero knows that this is an Interbus Receive Word.

It then sends the whole package onto the Avionics Bus using the Interbus Receive Word as a Command Word and the following words as the 10 data words.

The Display system receives these 10 data words at subaddress 16 and the transaction is completed.

The above example describes a request to transmit form of transaction. If we had organised the data transfer from the other end then we would have had a request to receive transfer which would have been set up as follows.

The Fuel Management System on the General Services Bus formulates one special data word the Interbus Receive Word which it places in subaddress 29 followed by the ten data words. A Vector Word to request to send eleven data words to the Avionics Bus is created and placed in the Remote Terminal Vector Word Register and the Service Request bit is then set.

The Interbus Receive Word would be:- 6 2 0 A Hex

The Vector Word would be:- 0 3 E B Hex

The General Services Bus Controller detects the Service Request and asks the Fuel Management Unit to transmit its Vector Word. This is decoded and the Fuel Management Unit is then asked to transmit eleven data words from subaddress 29. The General Services Bus Controller knowing that this is a message for the Avionics Bus from the Vector Word places these data words in subaddress 29 of its Remote Terminal on the Avionics Bus. It then sets up a Vector Word to send eleven data words to the Avionics Bus Controller and sets its Service Request Bit.

The Vector Word would be:- 0 3 E B Hex

The Avionics Bus Controller detects the Service Request and asks the General Services Bus Controller Remote Terminal to transmit its Vector word. This is decoded and the General Services Bus Controller Remote Terminal is then asked to transmit eleven data words from subaddress 29. The Avionics Bus Controller knowing that this is a message for the Avionics Bus from the Vector Word decodes the first data word. Because bit 10 is a zero it knows that this is an Interbus Receive Word and decodes the rest of the word accordingly. This amounts to using this word as a Command Word on the Avionics Bus to send the other ten data words to the Displays System at subaddress 16. The Displays System receives this data and the transaction is complete.

The examples given above are only two of a large range of acyclic interbus communications, the reader should be able to derive the other possible data transfers from the component parts of these examples.

With certain bus configurations it is possible to arrange shorter total transfer paths than given by these general techniques. In practice however the generality of these techniques is a very significant advantage, it is possible to add extra data transfers to a bus network without making any changes to the Bus Controllers, whereas a less general technique would not permit this.

4. SUBSYSTEM INTERFACE PROTOCOL.

To avoid synchronisation problems with Acyclic messages only one Acyclic message can be active per subsystem at a time. In interbus transfers once it has left the original bus then it is permissible to activate a further Acyclic message since the return path is a separate transaction.

In order to retain synchronism it is necessary to adhere to a strict protocol when transmitting Vector Words and receiving or transmitting the associated data. Two flags are used to control the process, the acyclic sent flag and the acyclic busy flag.

When a subsystem requires to transmit data the data and its associated Vector Word are placed on a queue in the subsystem interface storage area.

The subsystem interface software monitors the acyclic busy flag and if this is not set it then tests this queue and if it detects an entry it decodes the Vector Word and processes it accordingly.

If the Vector Word describes a request to send data to another Remote Terminal or a special interbus transaction then the data word/words are unqueued and placed in subaddress 29 transmit, the Vector Word is unqueued and placed in the Vector Word Register, the acyclic sent flag is set, the acyclic busy flag is set and the Service Request Latch is set in the subsystem interface.

The next Cyclic transaction from the Remote Terminal will have the Service Request bit set in its Status Word.

The Bus Controller upon recognising the Service Request will set up a Transmit Vector Word request to the Remote Terminal, the Remote Terminal transmits the Vector Word and clears the Service Request Latch in the subsystem interface. The executive decodes the Vector Word and sets up the data transfer. The subsystem by definition sends the data from subaddress 29 and when this occurs the Remote Terminal clears the acyclic sent flag.

The subsystem interface software must periodically (not more frequently than 10ms or less frequently than 200ms) test the acyclic busy flag and if it is set then it checks the acyclic sent flag, if it is clear then the acyclic busy flag should be cleared and that iteration of the subsystem interface software exited. Any time that the subsystem interface software is called and the acyclic busy flag is clear then the acyclic queue should be checked to see if there are any entries. If transactions are found on the queue they are then processed as discussed above.

This technique ensures that the retry scheme of repeat twice on original bus then repeat twice on alternate bus has sufficient time to run to completion if necessary before the subaddress data is overwritten by the following transaction in the event of there being one on the queue.

Timers must be maintained on the control flags and if a flag having been set is not cleared within 300ms then the flags should be cleared and that particular transaction requeued. If a transaction is requeued 4 times without succeeding then it should be abandoned to avoid clogging up the bus and some suitable recovery action taken.

The actual techniques used on the A.S.D.R. are more complex than the above description since there are other types of acyclic message using the queue than the interbus transactions described.

5. CONCLUSION.

These Cyclic and Acyclic Interbus Data Transfer techniques have been implemented on the B.Ae. Brough A.S.D.R. and are currently being used successfully in a complex data transfer environment. This environment includes message sequence tables which change with phase of flight, dynamically changed sequence tables to cope with failures in redundant systems, dual bus controllers with dynamic handover if one fails and broadcast message transfers.

Work is continuing on the expansion of the A.S.D.R. and many other features of data buses remain to be assessed in the coming months.

6. REFERENCES.

MIL-STD-1553B Aircraft Internal Time Division Command Response Multiplex Data Bus.

7. ACKNOWLEDGEMENTS.

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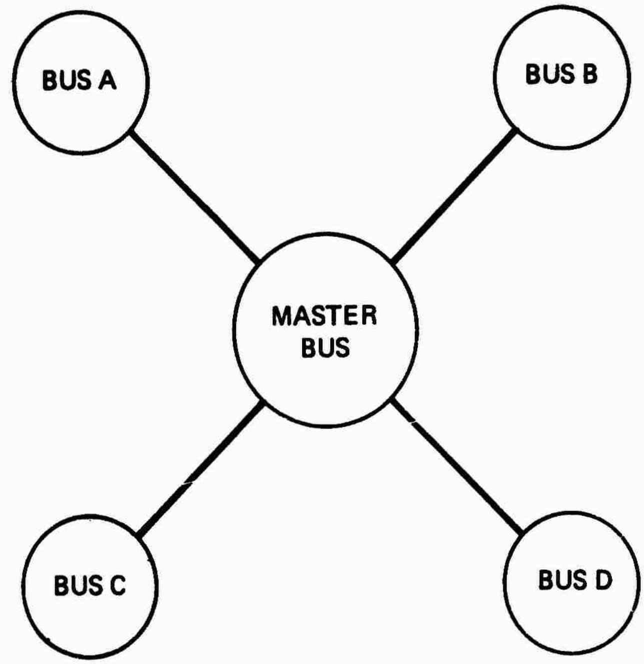

FIG.1

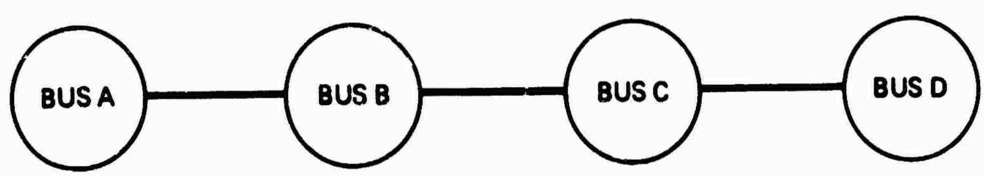

FIG.2

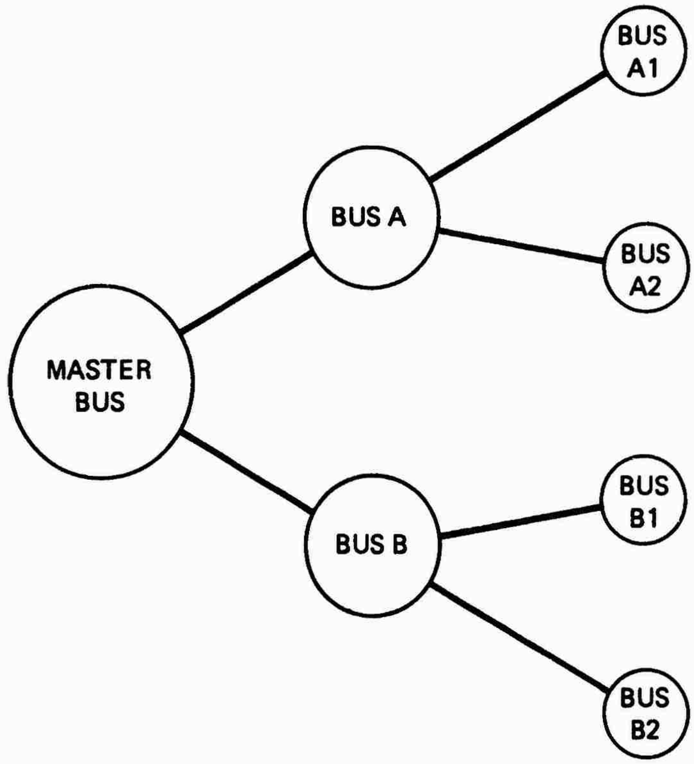
BUS A1
BUS A
BUS A2
MASTER BUS
BUS B1
BUS B
BUS B2

FIG.3

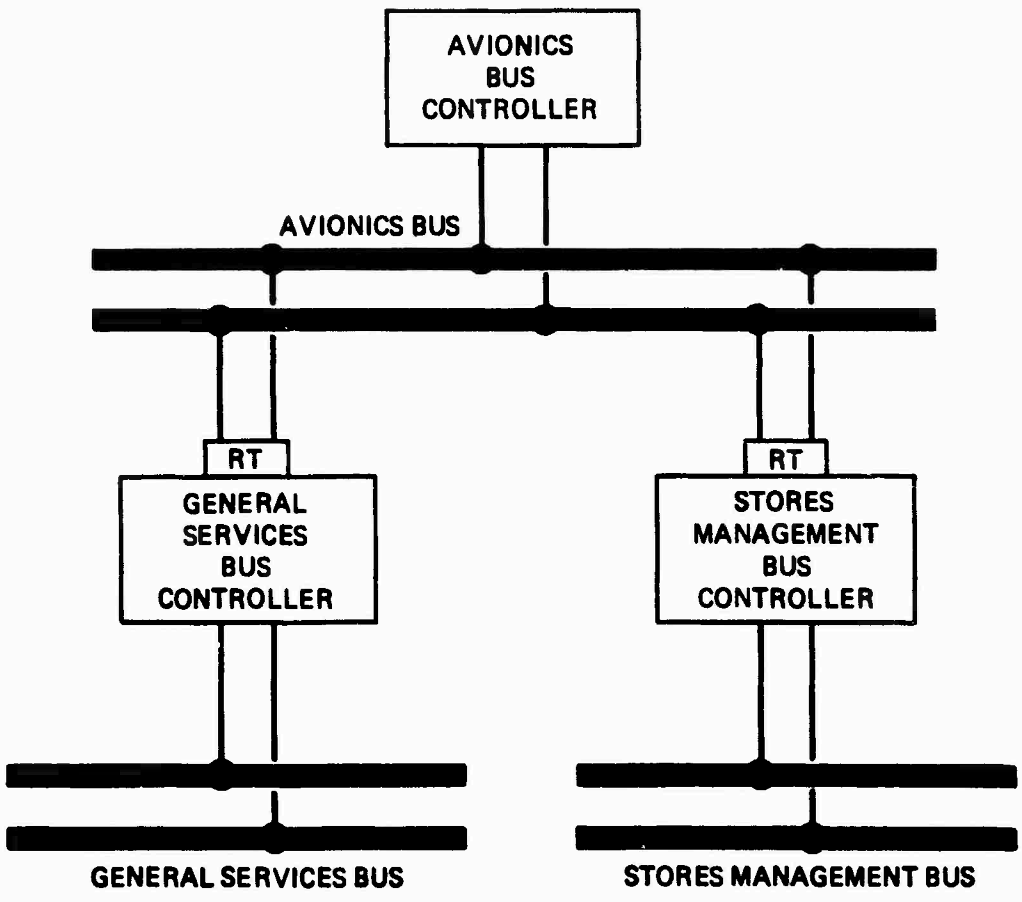
AVIONICS BUS CONTROLLER
AVIONICS BUS
RT
GENERAL SERVICES BUS CONTROLLER
RT
STORES MANAGEMENT BUS CONTROLLER
GENERAL SERVICES BUS
STORES MANAGEMENT BUS

FIG.4

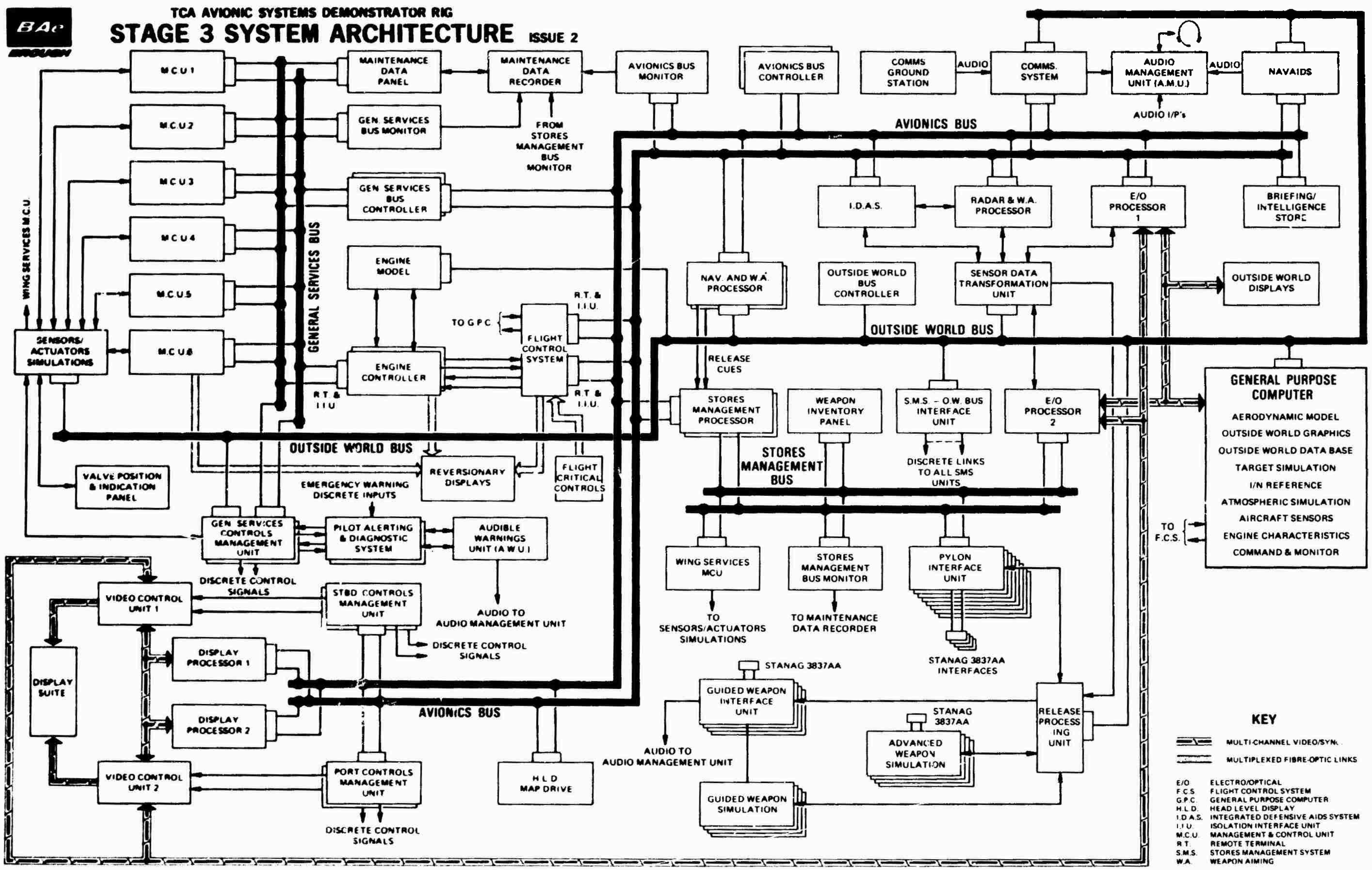
BAe
TCA AVIONIC SYSTEMS DEMONSTRATOR RIG
STAGE 3 SYSTEM ARCHITECTURE ISSUE 2
M.C.U 1
M.C.U 2
M.C.U 3
M.C.U 4
M.C.U 5
M.C.U 6
SENSORS/ ACTUATORS SIMULATIONS
WING SERVICES M.C.U.
VALVE POSITION & INDICATION PANEL
MAINTENANCE DATA PANEL
GEN. SERVICES BUS MONITOR
GEN. SERVICES BUS CONTROLLER
ENGINE MODEL
ENGINE CONTROLLER
GENERAL SERVICES BUS
MAINTENANCE DATA RECORDER
FROM STORES MANAGEMENT BUS MONITOR
TO G.P.C.
FLIGHT CONTROL SYSTEM
R.T. & I.I.U.
FLIGHT CRITICAL CONTROLS
REVERSIONARY DISPLAYS
OUTSIDE WORLD BUS
EMERGENCY WARNING DISCRETE INPUTS
GEN. SERVICES CONTROLS MANAGEMENT UNIT
PILOT ALERTING & DIAGNOSTIC SYSTEM
AUDIBLE WARNINGS UNIT (A.W.U.)
AUDIO TO AUDIO MANAGEMENT UNIT
DISCRETE CONTROL SIGNALS
STBD CONTROLS MANAGEMENT UNIT
VIDEO CONTROL UNIT 1
VIDEO CONTROL UNIT 2
DISPLAY SUITE
DISPLAY PROCESSOR 1
DISPLAY PROCESSOR 2
PORT CONTROLS MANAGEMENT UNIT
AVIONICS BUS
H.L.D. MAP DRIVE
AVIONICS BUS MONITOR
AVIONICS BUS CONTROLLER
COMMS GROUND STATION
AUDIO
COMMS. SYSTEM
AUDIO MANAGEMENT UNIT (A.M.U.)
AUDIO I/P's
NAVAIDS
I.D.A.S.
RADAR & W.A. PROCESSOR
E/O PROCESSOR 1
BRIEFING/ INTELLIGENCE STORE
NAV. AND W.A. PROCESSOR
OUTSIDE WORLD BUS CONTROLLER
SENSOR DATA TRANSFORMATION UNIT
OUTSIDE WORLD DISPLAYS
RELEASE CUES
STORES MANAGEMENT PROCESSOR
WEAPON INVENTORY PANEL
S.M.S. - O.W. BUS INTERFACE UNIT
E/O PROCESSOR 2
DISCRETE LINKS TO ALL SMS UNITS
STORES MANAGEMENT BUS
GENERAL PURPOSE COMPUTER
AERODYNAMIC MODEL
OUTSIDE WORLD GRAPHICS
OUTSIDE WORLD DATA BASE
TARGET SIMULATION
I/N REFERENCE
ATMOSPHERIC SIMULATION
AIRCRAFT SENSORS
ENGINE CHARACTERISTICS
COMMAND & MONITOR
TO F.C.S.
WING SERVICES MCU
TO SENSORS/ACTUATORS SIMULATIONS
STORES MANAGEMENT BUS MONITOR
TO MAINTENANCE DATA RECORDER
PYLON INTERFACE UNIT
STANAG 3837AA INTERFACES
STANAG 3837AA
GUIDED WEAPON INTERFACE UNIT
AUDIO TO AUDIO MANAGEMENT UNIT
GUIDED WEAPON SIMULATION
ADVANCED WEAPON SIMULATION
RELEASE PROCESSING UNIT
KEY
MULTI-CHANNEL VIDEO/SYN.
MULTIPLEXED FIBRE-OPTIC LINKS
E/O ELECTRO/OPTICAL
F.C.S. FLIGHT CONTROL SYSTEM
G.P.C. GENERAL PURPOSE COMPUTER
H.L.D. HEAD LEVEL DISPLAY
I.D.A.S. INTEGRATED DEFENSIVE AIDS SYSTEM
I.I.U. ISOLATION INTERFACE UNIT
M.C.U. MANAGEMENT & CONTROL UNIT
R.T. REMOTE TERMINAL
S.M.S. STORES MANAGEMENT SYSTEM
W.A. WEAPON AIMING

FIG.5

DISCUSSION

M.A.J.Burford, UK

Previous speakers have voiced the opinion that multi-layered buses may cause unacceptable time delays in the system. Certainly the use of a "common" terminal to provide a post box between the two buses would appear to have the effect of a lag built into the system. Have you managed to establish the maximum rate of interbus data flow and if so what is it? If the interbus data flow is to be minimised, have the bus functionalities been optimised in order to ensure this and if so could you please outline the methodology used to validate the choice of bus functions.

Author's Reply

We have not established a maximum rate of interbus data bus flow. Because of the data latency problems it is desirable to minimise interbus traffic rates as far as possible. Other considerations, however, (mainly bus integrity levels) prevent choosing the systems on the various buses to minimise interbus traffic. If data latency is a serious problem then there is perhaps a need for dedicated links between the affected systems. Bus latency is however only a part of the problem, asynchronous operation of processors and I/O buffering can have effects just as great if not greater. I believe that this needs to be addressed as a total system problem for each case. The acyclic interbus protocols described in the paper are intended to be used for signals which are transmitted only a few times per flight and the latency associated with the technique is not a problem. The latency of the cyclic technique is a function of the minor cycle rates on the intercommunicating buses; in general cases it averages at about twice the single bus latency.

A VIDEO BUS FOR WEAPON SYSTEM INTEGRATION

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General Dynamics Corporation
Fort Worth, Texas, 76101, USA

INTRODUCTION

The total costs associated with retrofitting an existing aircraft to integrate a new weapon are staggering. At the airframe manufacturer there are the costs of scheduling, engineering, drafting, developing shop plans, purchasing, receiving, kitting, storing, opening aircraft wings, installing, testing, qualifying, inspecting, ferrying, changing training manuals, training ground crews and defining logistical needs. The Air Force has additional direct costs of scheduling, planning for reduced fleet strength during retrofit, and training ground crews. And there are still other costs in defining the new weapons to be integrated, modifying the affected weapon delivery software, simulating, flight testing and crew training. To add a pair of new control wires to an existing aircraft could easily generate non-recurring costs of millions of dollars!

MIL-STD-1760 is a far-sighted approach to eliminate most of these costs and to reduce many of the others. The standard defines the mechanical and electrical characteristics of the connector interface for new weapons. As a joint Air Force/Navy standard. all new weapons will be required to be designed such that all command, control, and communication with those stores will occur through these pre-defined connector pins. Once an aircraft is built to meet the connector requirements, then any new weapon can be added by only changing the weapon delivery software. The purpose of this paper is to highlight the problems an airframe manufacturer faces in adopting the standard, and to focus on the solution of one of these problems, viz, the video requirements of the standard.

MIL-STD-1760 SUMMARY

The goal of MIL-STD-1760 is to define for all times the electrical interface for new stores. All the electrical cabling needs, computer interfaces, and weapon system architecture can be built into a new aircraft today, and they will not need significant (or any) changes for the foreseeable future. The airframe manufacturer has strong impetus to meet the standard at whatever costs today, to be in a position to readily accomodate the needs of his customers in the future. Stores developers have the same impetus since their products can now be integrated into all new aircraft in a straight forward fashion. Figure 1 shows the locations where a -1760 connector is likely to exist on the airframe. The -1760 connector can reside at either the wing hardpoint, or within a rack. The standard attempted to provide a mix of interface types sufficient for all power, command, control and communication with a store. Figure 2 and the accompanying table show the connector pin arrangement and the signal types. It is seen thet power, serial digital and discrete signal types have been provided.

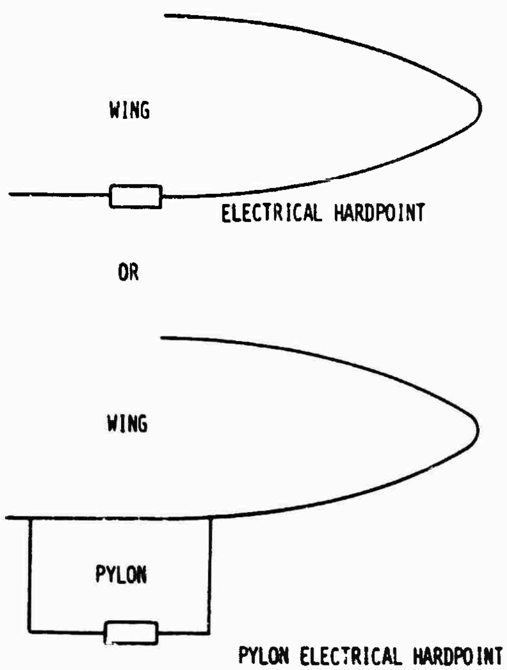


FIGURE 1. MIL-STD-1760 CONNECTOR LOCATIONS TO SERVICE A STORE

NOMENCLATURE	CONTACT LOCATION
FIBER OPTICS BUS A	Y
115V AC RETURN	Z
RELEASE CONSENT	1
HIGH BANDWIDTH 4	2
HIGH BANDWIDTH 3	3
ADDRESS BIT A_3	4
HIGH BANDWIDTH 1	5
ADDRESS RETURN	6
ADDRESS BIT A_2	7

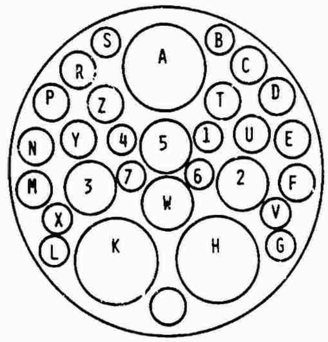


FIGURE 2. MIL-STD-1760 CONNECTOR PIN ASSIGNMENTS

CONTACT LOCATION	NOMENCLATURE
A	AUDIO
B	INTERLOCK
C	28V DC POWER 1
D	POWER 1 RETURN
E	POWER 2 RETURN
F	28V DC POWER 2
G	ADDRESS PARITY
H	MUX BUS B
J	115V AC,ØC
K	MUX BUS A
L	ADDRESS BIT A_0
M	115V AC,ØB
N	270V DC RETURN
P	115V AC,ØA
R	270V DC POWER
S	INTERLOCK RETURN
T	STRUCTURE GROUND
U	FIBER OPTICS BUS B
V	ADDRESS BIT A_4
W	HIGH BANDWIDTH 2
X	ADDRESS BIT A_1

In spite of all these positive features and benefits, airframe manufacturers are not stumbling over themselves to universally incorporate the standard. Fighters and fighter/bombers reflect a compromise of drag, lift, fuel and avionics. If an aircraft is to have a reasonable number of store stations and all of them are to be compatible with -1760, then a rather large channel must be created for the cabling; an area that otherwise could have been used for fuel. Is it reasonable, the airframer may ask himself, to expect a store on a wing tip that would require 30 amperes and two RF lines? Figure 3 conveys the magnitude of the problem for a generic aircraft with a reasonable number of weapon stations. Perhaps it is more reasonable to designate certain weapon stations for air-to-air, others for air-to-ground, some for pods and e few general purpose.

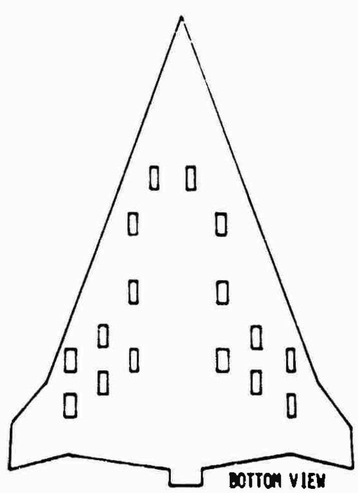


FIGURE 3. MULTIPLE STORES STATIONS FOR LARGE SURFACE AREA AIRCRAFT

An Air Force study (VIDS program, AFAL/AAAT) predicted a future aircraft with as many as 50 weapon hardpoints. A fully compatible -1760 connector at all those locations would constitute a very sizeable cable harness. It would be easy to adopt a weapons loading philosophy of dedicated stations for this sort of vehicle, providing power, video, RF, and MIL-STD-1553, only where it is likely to be needed. Unfortunately, the history of technology development has one clear lesson--very few people are able to forecast the future with any accuracy, and no one can predict who those people are. To rule out the possibility of a wingtip-mounted store in the 1990's that would require 30 amperes, -1553, video and RF would be shear folly. (The simple fact that store designers can assume those interfaces are available, almost assures that someone will design something to use them.) After losing an argument with himself the airframer has only one intelligent answer. Meet the standard.

What the airframer must then do is reduce the problem to one of identifying a top-level integration philosophy that will meet the anticipated future needs. Given that everything is necessary, the system designer needs to define how it will all be managed. The questions become: who is in charge; how will the cable routing occur; if additional electronic elements are necessary, how will built-in test occur; how can the network integrety be evaluated ;where does fault recording occur; and so on. These questions are answered within the physical limits of the airframe. For example, the designer may limit the stores loading in total power consumption, number of active RF lines, etc. Even when this approach is followed, there are some especially difficult problems. General Dynamics is dedicated to providing full compliance to -1760 at every station, but the implications of some of the requirements are difficult at best. One of these is the two signal interfaces in the standard called "high bandwidth 3&4, video".

-1760 VIDEO REQUIREMENTS

The standard defines the video requirements in less than two pages. Electrically the two video pins are to be bi-directional ports with 20 MHz bandwidth and a characteristic impedance of 75 ohms. The channels are to be a high quality conduit for 525 line video in RS-170 format or 875-line video in RS-343 format. There are no other uses defined for these pins, but they are open for any signal falling within a 20 MHz bandwidth. Implied in the dual, bi-directional aspect of the standard is the provision for communication between stores. It is easy to anticipate a store with a requirement for correlating video from several weapon stations in order to, say, slew a video, seeker head in a weapon from a pattern recognizer in another pod. Looking to the future, the system designer can visualize a need for full bi-directionality in the weapon station video, as well as simultaneously displaying it in the cockpit. What this describes is a sizeable network within the aircraft to achieve this need. For a vehicle with the number of stations described in the VIDS study, it is a potentially very complex network. This network becomes even more complicated when one recalls that the extremes of temperature, shock and vibration are experienced in the wings. What follows is a discussion of alternatives to meet the video needs.

VIDEO DISTRIBUTION SYSTEM ALTERNATIVES

Electro-mechanical Switching Matrix

There are numerous ways to meet the requirements of the standard while meeting the needs of the vehicle. There is no one right approach for all aircraft, rather different answers for different circumstances. The simplest network is one composed of electro-mechanical relays. This method requires coaxial cables to run from weapon stations to a central switching matrix that acts like a telephone operator affecting the required connections. This type network becomes unique to the host aircraft. The size and complexity of the switch is determined by the number of stations, the maximum number of simultaneous communications desired, and the maximum number of sinks required for any source (i.e., is it to be a simple point-to-point network, or are multiple destinations desired: station-to-station-to-cockpit?). Figure 4 shows a simplified version of a switch allowing two simultaneous paths and only one destination. When mechanized in an aircraft a simple switch can be centrally located, or a distributed network can be constructed with local matrices. For example each wing could have a matrix that is tied to a fuselage matrix.

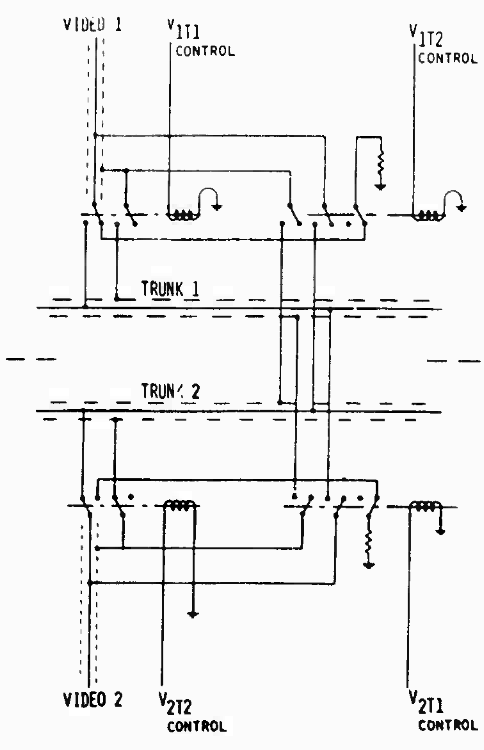


FIGURE 4. ELECTRO-MECHANICAL SWITCHING MATRIX ELEMENTS. SHOWS HOW A VIDEO LINE CAN BE COUPLED TO ANY OTHER VIDEO LINE USING RELAYS

The major advantages to this approacb ar~ low cost, multiple vendors, and the switching centers can be built without power supplies--the relays deriving their excitation from the controlling source. Control over the relays could come from the weapon station interface units in the stores management set, such that the stores computer would activate the connection.

There are many weaknesses in sucb a network. Relays are not a favored technology. They tend to wear out easily and their durability is adversely affected by vibration. The number of relays required to construct a fully inter-connectable matrix that is capable of several simultaneous channels grows in a geometric proportion. This approacb does not expand easily either, to add another station causes a redesign of the matrix. A final issue is the mixed blessing of a passive matrix without a power supply. The controlling sources must have discrete power drivers with all the associated filtering to protect the master unit.

Solid State Switch

Many of the objectional aspects of mechanical relays could be removed by constructing the matrix with solid state relays. Semiconductor technology certainly has the potential for better reliability than a mechanical system. The power requirements of the controlling signals could be reduced (probably via a multiplex bus), and the costs could be influenced by silicon economy of scale. Unfortunately, this alternative trades one set of problems for another. The standard calls for 20 MHz channel bandwidth--a range not currently accomodated in any component, to the best of our knowledge. The network is to be bi-directional, implying a rather sophistocated circuit module to prevent feedback. And finally the matrix would become a powered unit requiring built-in tests, self-test and a fault isolation/reporting function. Figure 5 is a graphic representation of the functional elements required in a solid state switcb.

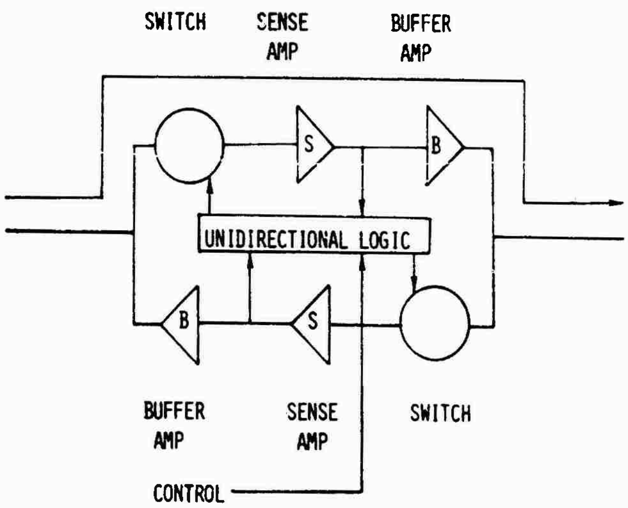


FIGURE 5. CIRCUIT ELEMENTS IN A BIDIRECTIONAL SOLID STATE SWITCH TO PREVENT FEEDBACK

Fiber-optic Network

A technology with features that should lend themselves nicely to video distribution is fiber optics. Optical fibers are all dielectric, hence immune to electromagnetic effects. Even in a high electrical noise environment the fibers themselves will contribute nothing to corrupt the signals being carried within them. The fibers are physically small and can be cabled such that many separate signal paths are contained within a small diameter, very flexible cable. A network can be visualized that employs optical fibers and a solid state switching approach. Figure 6 is a presentation of a distributed network with local switching and multiplexing in the wing and a central interconnect in the fuselage. Optical fiber bundles interconnect the matrix elements.

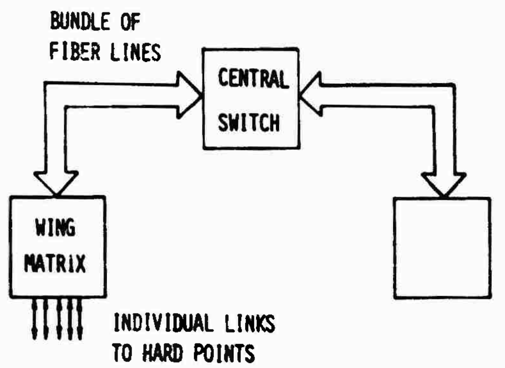


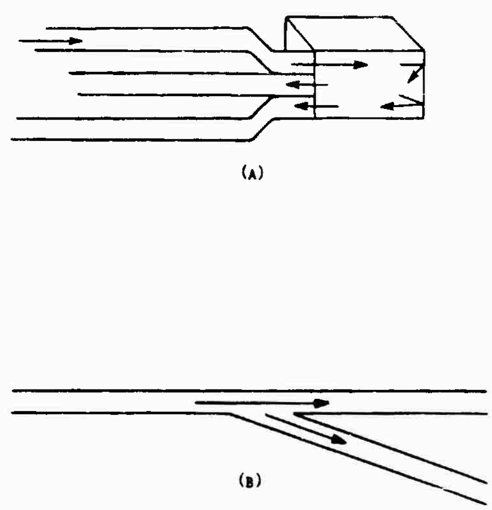
FIGURE 6. DISTRIBUTED FIBER-OPTIC NETWORK

This network is subject to the same drawbacks as the wire version discussed above, plus the added cost of a transmitter/receiver pair at each end of the optical fibers (together with a more complicated fault isolation requirement). The benefits that are added are noise immunity and physically smaller interconnects between matrix modules. (The entire subjects of field maintainence and environmental effects on fiber-optic connectors will be ignored in this paper.) Where optical fibers begin to make sense is when the network described above can be converted to a totally passive distribution system. That is, converting the electro-optical switching elements into optically passive elements. If it were possible to switch or distribute the light from the originating fiber to the proper destination without going through optical-to-electrical then electrical-to-optical conversions, a considerable cost and complexity savings could be realized.

Several methods of achieving light-in, light-out networks have been developed, and they have varying degrees of success for small networks. Figure 7 is a schematic presentation of two passive networks. The star coupler in figure 7a will take the incoming light from one fiber and uniformly distribute it among all the fibers attached to the coupler. This technique has been demonstrated for several years in the form shown in the figure, and in a form that has separate transmit and receive fibers. The point to notice in this scheme is that the sum of the exiting optical power is equal to the input power minus any insertion losses. Thus a perfect 16-port coupler will create 12 dB optical power attenuation. Typically the connector at the coupler will contribute another 1-2 dB and the internal mechanisms are not perfect, so a realistic 16-port coupler might have a total insertion loss of 20 to 24 dB. This power loss cannot be made up by increasing the optical source power in practical systems. Thus the network has a finite (and small) amount of optical power that will be considerably attenuated before it is received by a noise-limited detector (typically a PIN photodiode). Preserving an adequate signal-to-noise ratio essentially limits the number of terminals on the network. The bandwidth of the detector preamplifier establishes a noise floor, the optical source (ideally an LED, rather than a more expensive laser diode) establishes the amount of optical power in the network, and the passive network's attenuation will combine to determine the final signal-to-noise ratio.

Frequency multiplexing techniques to achieve simultaneous channels one must be challenged immediately because the increased bandwidth raises the noise floor in the detectors. A different multiplexing technique that is being pursued in earnest in the fiber-optics industry, however, is "color" multiplexing. Optical sources--LED's and laser diodes--can be made very narrow band, and by using semiconductor doping techniques the frequency ("color") of the emitted light can be shifted adequately so that several "shades" of infrared can be transmitted in the same fibers without significant interference. Most detectors are silicon based, hence rather broadband, permitting the same detector to receive any of the shades and filter techniques have been developed to permit a detector to the unique shades.
Once developed, color multiplexing will be useful for many systems. Right now the color selection in the transmitter is a semiconductor process, so a network designer would need to be clever to avoid conditions where transmitters of the same color need to communicate at the same time.

Figure 7b is a bi-conical tee. This is the fiber-optic version of a weighted power splitter. A small portion of the power in the network is routed off to a detector with the remainder continuing along the main highway. The main advantage in this approach over star couplers is that the optical octopus of the previous example can be avoided, reducing the amount of cabling. All the limitations of the previous scheme still apply--insertion losses, bandwidth restrictions, source power, etc.



(A)

(B)

FIGURE 7. PASSIVE OPTICAL COUPLERS
(A) REFLECTIVE (B) BI-CONICAL TEE

Digitized Video

Digital techniques are frequently used for distribution and manipulation of analog signals because once digitized, the signal is unaffected by corrupting effects of traditional electrical noise sources. To preserve a 20 MHz channel, the Nyquist criteria says at least a 40 MHz sampling is required. Assuming that one could reconstruct the original waveform on the fly when sampled at this rate, and also assuming that ten bits of digitizing resolution is adequate to recreate a smooth picture (60 dB), then a 400 MBits/sec channel would be required. A data compaction technique could obviously reduce the bandwidth; indeed, dramatic compression has been achieved for video imagery. Figure 8 depicts the central elements in such a scheme.

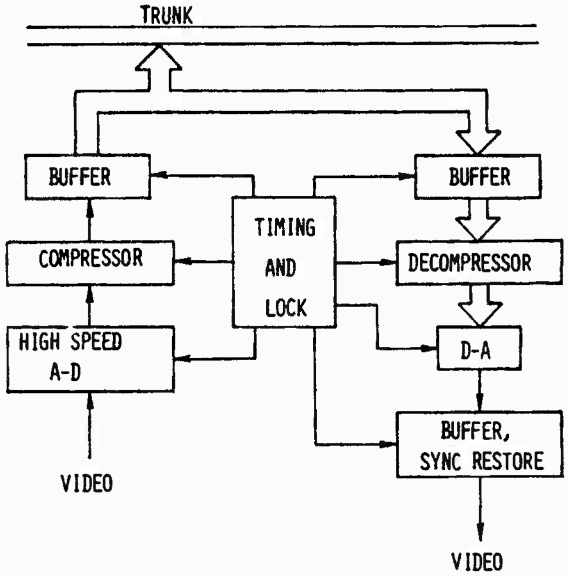


FIGURE 8. ELEMENTS IN A DIGITAL VIDEO NETWORK

This approach becomes messy when simultaneous communications are required. The actual network bit rate could be increased to permit time division multiplexing on a common bus, or multiple paths could be employed driving the design into a solid state switch/digital network analogous to our second example. Whenever the bit rates begin to exceed 30 MBits/sec the distribution path takes on additional complexity since transmission line effects will become serious problems. And finally there is some question as to the exact nature of bandwidth compression that can be tolerated in a weapon sensor video system. A compression technique that works fine for humans looking at pastoral scenes may be worthless when trying to locate a partially hidden tank.

Video Bus

The technique that appears to hold the highest promise for wide application is the video bus. Figure 9 shows an overview of this approach. Conceptually this is a single video highway on which video channels are frequency multiplexed, much the same as cable television. And in fact, this method is realizable today because of the progress that has been made in the cable television industry in miniaturization and ruggedness.

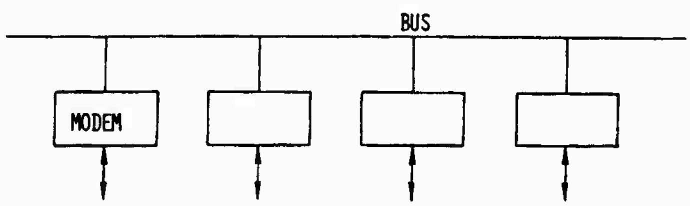


FIGURE 9. VIDEO BUS NETWORK ARCHITECTURE

VIDEO BUS CHARACTERISTICS

The basic philosophy behind a video bus is that it is possible to allocate frequency channels on a coaxial bus and construct transmitters and receivers capable of operating over those channels without interfering with each other. Figure 10 indicates conceptually how the channelization would work. Carrier frequencies are established for a number of channels. These carriers are selected in the spectrum such that a 20 MHz band about them will not have significant overlap into the adjacent channel, thereby creating a guard-band region between the channels. The total number of channels is determined by the number of anticipated simultaneous required, plus some spares. The actual frequency range over which the network works is a function the components available to do the job and will be transparent to the system user. In fact, it does not matter that the channels be equally spaced or contiguous; it only matters that the network elements are easily able to transmit and receive over them.

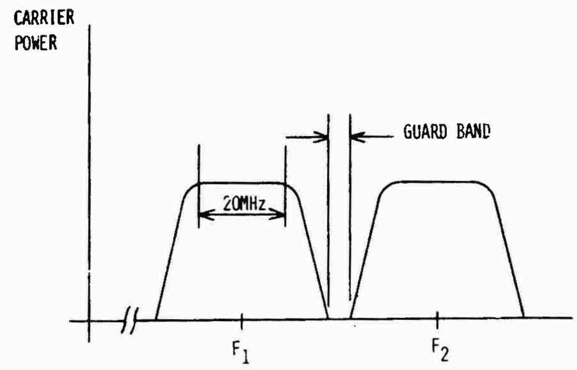


FIGURE 10. ELECTRO-MAGNETIC SPECTRUM SUBDIVISION FOR VIDEO BUS

The key hardware elements in this network are modems, couplers, a cable trunk line, digital command and control, and locally multiplexed video input and output. Figure 11 depicts these elements in a simplified terminal. The modem contains a transmitter that will modulate baseband 20 MHz signals at predetermined carrier frequencies; and a receiver that will perform the reverse operation. Included in this circuitry is sufficient filtering, prescaling and signal conditioning to preserve a useful signal-to-noise ratio and eliminate corruption by other channels. The coupler connecting the modem to the bus has two features essential to making the network work. It must be a passive device thereby not creating modulation products, and it must address power ratios, so that it only draws off the amount of power required by that terminal. The cable trunk line,the bus itself, is a terminated transmission line of either coaxial or triaxial cable. The only essential constraint on it is assuring that it remains a balanced transmission line. For example, techniques of impedance matching are needed for the coupler attachments to preserve waveform quality. The modems need to be controlled by a digital network so that several things will be possible. First, of course, is tuning the transmitter and receiver in a modem. This operation should require a simple channel selection code from the host system and the command and control network would take care of actually setting the proper frequencies. In this way the host system would only need to know that there exists some number of channels and that they have a unique identification. The host would not know or care anything about what the channel assignments mean to the modem electronics; in exactly the same way most home television viewers change channels. The digital system should also command and monitor built-in tests over the modem and report the results to the host. Wrap-around tests on the transmitter/receiver, as well as monitoring key functions are possible to determine the health of the hardware. Self-test over the entire network would likely invoive a human viewing a display.

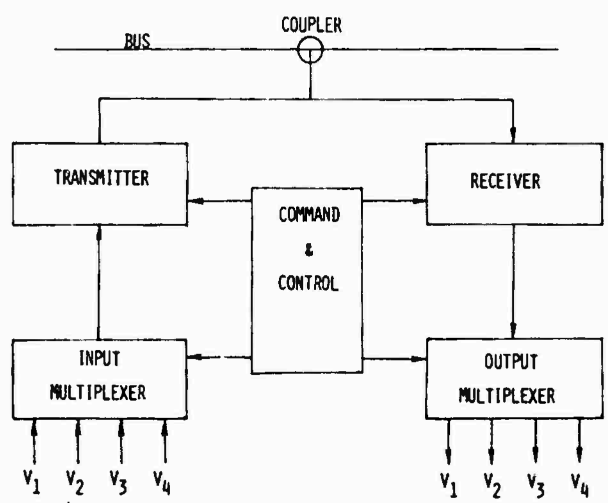


FIGURE 11. CENTRAL ELEMENTS IN A VIDEO BUS TERMINAL

We have assumed this hardware will reside within another element in the aircraft and that element will have a MIL-STD-1553 interface. thus total network control will be via a -1553 system. To require a separate -1553 bus to control the video bus is undesirable in terms of cable and electronics, and is redundant in a stores management set. A small addition to the video input/output circuitry that greatly enhances the operational features of this approach is a four-to-one multiplexer. This feature permits up to four sources or sinks to use each modem. In the case of a stores management set it is common to find a weapon station with several different attachment points. These are required to be able to physically carry different store types at a given station. Normally, only one of the hardpoints is in use at a station at one time, thus a four-to-one multiplexer permits a single modem to service the lot. Finally a word about software. In order to simplify the flexibility of this approach as a building block, there is no resident processing requiring software. The command and control circuitry may contain a micro-sequencer, but its firmware is not likely to change in a mature system. This entire concept bus actually been made possible by advances in the cable television market. The manufacturers of video electronics have made dramatic progress in LSI of video processors. One need only look at a schematic of the latest television monitors to realize that what used to take a jungle of components is now done in a single integrated circuit. But beyond the integration, the commercial parts designers have had their eye on other goals as well. It would not make good economic sense to design a chip that would only handle the 525 line encoding of the United States when the same circuit could possibly be designed to meet the needs of Europe, Brazil and others. So the off the shelf circuitry for conventional home television in some cases actually has considerably more bandwidth than needed. More importantly, it is designed with processes that can be pushed to accommodate the 20 MHz required by the standard. Secondly, as a chip manufacturer the feature that will enhance a product when there are several competitors with similar electrical specifications is reliability. The cable television market has a self-imposed standard that is nearly as rigorous as the military market. And again, in achieving their own goals, the designers of those circuits used processes that are amendable to MIL-STD processing. In short, a video bus is possible because of the cable television industry.

IMPLEMENTATION IN AN AIRCRAFT

It is visualized that the video bus would become a sub element of a stores management system (SMS). Figure 12 depicts a stylized multibus avionics architecture. This particular arrangement uses two -1553 buses to control and coordinate the avionics suite and a third -1553 bus to control the SMS. The SMS would consist of a central computer directing operations and store interface units (SIU) to communicate with and release stores. The SIU would contain all the required electronics to provide a -1760 interface, as well as the discretes for pre-1760 stores. The video bus electronics would reside within the SIU, and a coaxial bus would run parallel to the SMS -1553 bus. Commands to the video bus modems that would cause them to change channels, perform wrap-around tests, or reverse from a transmitter to a receiver would be issued by the SMS computer via its -1553 interface to the SIU's. The SIU would translate these instructions as it does for any other function in the system.

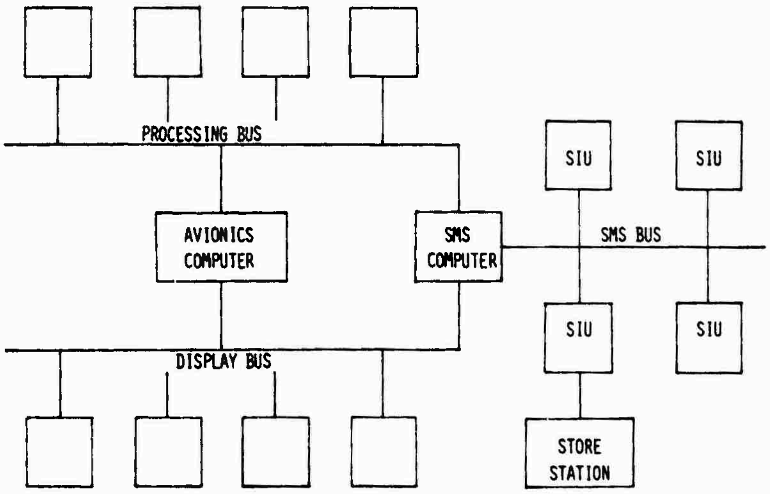


FIGURE 12. MULTI-BUS AVIONICS ARCHITECTURE

A portion of the operational flight program for the SMS computer would contain the -1760 characteristics for each store type. Another portion would contain the logic to interconnect the -1760 stores carried at any time into a useable configuration. For example this logic, once informed of the stores complement on the vehicle, would assign video channels for video weapons or E-O pods; would attach to the avionics bus those stores requiring -1553 communication; would interconnect those pods with RF link connections; and so on. In operation the pilot could carry to the vehicle a memory device containing mission plans, communication data, threat locations and stores data. The mission computer would use the data to initialize the system without further pilot interaction. Once airborne the pilot could call up video from any store station from a pictorial menu of options existing on his plane at any time, displayed on his multipurpose displays. The actual channel assignments would be transparent to the pilot. Figure 13 depicts the sequence in the video hook-up.

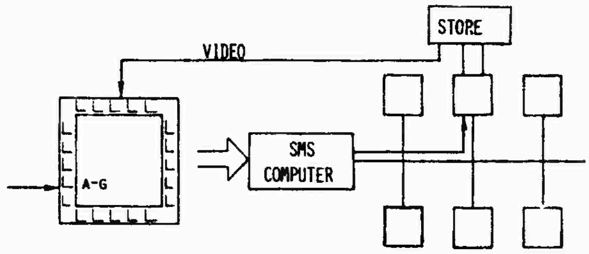


FIGURE 13. AUTOMATIC OPERATION OF VIDEO SELECTION

An air-to-ground mode is selected and the system automatically steps through a sequence that among other things routes video from an appropriate weapon to a display. That sequence within the SMS computer would inventory the available channels, command an assignment, run BIT, confirm the channel is good; then latch up the connection. If the channel should be noisy for whatever reasons, it is visualized that a "reassignment" switch could always be part to a multipurpose display format. When the pilot presses this switch the SMS computer automatically would repeat the channel selection process and delete the failing channel from the list of available choices.

SUMMARY AND STATUS

This paper describes

What has been described is a generic video bus concept that is realizable within the current state of the technology. A video bus can be achieved with a small set of components, probably in a pair of hybrid packages. Such a system could be built in a fundamental building block, applicable to any new aircraft design (as well as virtually any network requiring multi-channel video). The growth of commercial cable television has made miniaturization possible, although there is still some development required to meet the -1760 20MHz requirement and a full military temperature range.

MIL STD

NETWORK COMMUNICATIONS FOR A DISTRIBUTED AVIONICS SYSTEM

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ABSTRACT

Due to the postulated 1990's threat environment advanced avionics architectures are experiencing demands for increased performance which have led, in part, to increased processing requirements and system complexity. As more processors are added to the control environment of sophisticated military aircraft, the choice of processor interconnection topology and methodology assumes greater importance. This choice profoundly influences information throughput, reliability, survivability and integrity throughout the weapon system. The ability to rapidly exchange/transfer information among processors and devices is critical if one is to develop a reliable, effective, communication system.

This paper addresses basic communication techniques which could serve as candidates in satisfying the network communication requirements of an advanced avionics architecture. Features of each technique are examined to ascertain the performance of these multi-access protocols in terms of developed system-driven criteria.

1. Integrated Avionics System: An avionics system is an assemblage of elements which perform a particular set of weapon system related functions (e.g., navigation, weapon delivery, flight control, etc.). Presently, each of these functions is performed by autonomous subsystems consisting of various combinations of similar and standardized elements (processors, sensors, etc.). With few numbers of these large basically independent subsystems, the interconnection has been accomplished through the use of 1 megabit multiplex data buses (1553B). However, since many of these subsystems consist of common elements, it seems reasonable that a lower level connectivity philosophy could result in a more reliable, and efficient system design.

This new system design would represent a more highly integrated and cooperative avionics system with the attendant advantages of reduced weight, volume and power consumption through the multifunctional use of system elements. This multifunctional use provides numerous benefits: (1) a single set of sensors can be used to satisfy different requirements; (2) sharing of processing resources to satisfy diverse processing requirements; and, (3) increasing fault tolerance through system resource allocation. These benefits, however, come at an increased cost to the communication system. New requirements are now placed on the communication network--high bandwidth, many data sources, sinks, demand for increased reliability.

These new architectural and functional concepts require the communication system to now handle internal subsystem data traffic heretofore transparent at the system level. For example, the high-bandwidth traffic between the inertial instruments and the navigation computer is not visible beyond that subsystem. In a fully integrated system, each of the inertial instruments is a shared resource, and the data traffic between them and the various traditional functions (navigation, autopilot and fire-control) and advanced avionics system functions (TF/TA/OA) must be supported.

It is clear that when a highly integrated avionics system is compared to more conventional designs, the numbers of communicating data terminals have increased greatly. Thus, the communication system is dealing with a multiplexing problem made more complex by an increased number of data sources and sinks.

Finally, the integrated avionic system demands a more reliable communication system. Previous combat aircraft weapon systems employed autonomous subsystems, each of which minimized the flight-safety implication of subsystem-to-subsystem communication failures. While some data was exchanged, which allowed subsystems to optimize their performance, degraded modes and contingency control within the subsystem provided safe control alternatives, even if inter-subsystems communication were to fail. In effect, from a redundancy management perspective, the integration of the avionics system allows significant reduction in the number of sensors, displays, processors, etc., but at the expense of increased connectivity and reliability requirements for the data communication system.

2. Limitations of Current Data Bus: The existing bus standard is MIL-STD-1553B. This standard is the recognized 1 MBIT Command/Response Multiplex Standard which has evolved over the past 10 years and represents the first significant step towards more integrated system designs.

Though MIL-STD-1553B will continue to be used in the years to come, the more highly integrated system designs of the future as well as current avionic system designs have identified architectural limitations caused by the standard. The standard does not solve the generic problem of multiple high rate users in the network. To circumvent this problem in present aircraft, the system designers have employed composite systems of hierarchical bus structures each operating per 1553B and dedicated wiring. However, hierarchical bus topologies suffer transport delay when data must be communicated between buses. Scheduling and coordination of data transfer between buses in command response systems becomes a problem in that software in many devices must be synchronously controlled which further degrades real-time performance.

What must be developed, is a data bus capable of handling the architectural problems which currently exist as well as those of futuristic avionics networks. It has been suggested that the next generation bussing standard be tailored to satisfy a specific type of application. The bussing approach optimisation would revolve around a proposed non-command/control bursty traffic environment involving mass data exchanges between for example, stored electronic terrain maps, stored threat data, stored threat data, stored mission plan programs and the required processors to support new functions such as terrain maskings for improved low level penetration survivability. It is the intent of this paper to analyze various protocols from a total systems point of view; if it can be shown that a single bussing approach can be applied across many applications, albeit, sub-optimally but adequately on an individual case-by-case basis, then the more generic bussing approach should prevail. The data as to the final position on this issue has not been fully compiled, however, in anticipation of support of a generic capability the following analysis provides preliminary insight to potential candidates.

3. Selection Criteria: Before a data bus protocol capable of supporting the avionics architectural needs can be chosen, system driven criteria must be identified. The following have been identified as important criteria which a data bus protocol analysis must address:

- Throughput/Response
  - Effective Link Level Data Throughput
  - Data Latency
- Message Structure
  - Addressing Capacity
  - Broadcast Capability
  - Data Block Size
  - Content Addressability
- System Integrity
  - Monitorable
  - Testable
  - Ease of Initialization
  - Data Link Assurance of Receipt
- Fault Tolerance
  - Fault Detection
  - Fault Containment
  - Fault Isolation
  - Recovery Reconfiguration
- Adaptiveness
  - Incorporation of New Technology
  - Compatible with Old Mechanisms
  - Parameterization Capability
- Flexible Network Control Strategy
  - Central Control
  - Distributed Control
  - Synchronous
  - Asynchronous
- Cost/Complexity
  - Non-recurring Hardware and Software Costs
  - Recurring Hardware and Software Costs
  - Support Costs
  - Weight, Size, Power

With the use of a Decision-Aiding Algorithm, each of those criteria and their sub-criteria were ranked in order to achieve a weighting by which a protocol could be evaluated. As can be seen by the choice of the evaluation criteria, system design issues were considered to be of prime importance - the data bus protocol definition should be accomplished by a top-down approach. Although not specifically listed as criteria, system design issues such as system control procedures and executive/operating system impacts were often major factors in setting criteria values. Detailed definitions for each of the evaluation criteria are described in the following paragraphs.

Throughput/Response - Throughput is a measure of the rate at which a system can transfer data among its terminals. Response time is primarily a function of the flexibility and assignability of the allocation scheme which has implication in terms of throughput and data latency.

- Data Latency. This is the time delay from data reception at a transmitting node's data link level through data reception at a receiving node's data link level. This implies transmission of the data across the physical bus medium.

- Effective Link Level Data Throughput. This criteria addresses the issue of sustained throughput of data from data link level between two nodes. It is important to distinguish between actual user data throughput as opposed to percentage utilization or loading of the physical transmission medium.

Message Structure. The overall message structure should support a system in which any task can reside in any processor at any time. The command, address, and data block structure should allow sufficient flexibility to handle any possible task or the future expansion of the system to new tasks.

- Expandable Addressing - A provision to allow system expansion either directly or indirectly.

- Broadcast Capability - A system mode by which messages can be transmitted to all terminals simultaneously.

- Block Transfers - A block transfer mode of variable length data blocks.

- Content Addressability - Accommodation of data transfer based on message content or task.

System Integrity - The degree to which a system is dependable. The ease by which the system can be tested and monitored for conformance to requirements.

- Monitorable. A failure in the bus allocation mechanism should be quickly detected and immediate recovery initiated. This is usually accomplished by a monitor. The bus allocation method should be straightforward so as to simplify the amount of hardware required in the monitor function.

- Testability. This criteria addresses how well the protocol supports completeness of testing and facilitates repeatable or predictable results (i.e., transmission of messages on the bus). The main idea behind this criteria is testing, especially in the case of large, complicated avionic systems.

- Initialization. This criteria is a measure of how well a bus communication system supports initial configuration of a system on initial powerup.

- Data Link Assurance of Receipt. This criteria addresses the issue of how well the protocol supports the assurance of good data through the data link level (ISO level 2).

Fault Tolerance. The capability to endure component errors and/or failures without causing total system failure. An important aspect of fault tolerance is recovery, which includes fault detection, fault containment, fault isolation, and reconfiguration. Hence, fault tolerance will include the following areas:

- Fault detection - ability of a system to determine the occurrence of erroneous operation.

- Fault containment - measure of the extent to which the system prohibits errors and/or failures from propagating from the source throughout the system (i.e., a ripple effect).

- Fault isolation - isolation of a failure to the required level so as to be able to reconfigure. That is, to isolate a failure to a "component" so that it may be disabled or switched off and the system reconfigured without that component.

- Reconfiguration - what mechanisms are provided and how easy are these mechanisms employed to reconfigure a system after a failure has been detected and isolated. This may include the process of reassigning processing tasks from one processing component to another to accommodate a failure or change in mission requirements. It necessitates reassigning data flow paths.

Adaptiveness. The protocol should lend itself to flexibility. It should allow for new technology advances and their companion requirements.

- Incorporation of New Technology. This criteria addresses the issue of how easy the protocol can incorporate new technology (i.e., fiber optics, higher bus speeds, broadband, etc.). Potential benefits include improved capability and performance and the maturation of standards.

- Compatible with old mechanisms. This criteria supports those elements which are already in existence for current standards (hardware, software, control strategies).

- Parameterization Capability. This criteria addresses the requirement of a flexible protocol developed by parameterizing those elements which can be so structured.

Flexible Network Control Strategy. Various networks currently exist, therefore, a common data bus for these network would prove to be very beneficial.

- Central Control. The capability to be controlled from one master - be it stationary or non-stationary.

- Distributed Control. The capability to be controlled from many points in a system.

- Synchronous Messages. This criteria addresses the issue of how well the protocol supports the transmission of a series of messages at a known apriori sequence and time or time interval.

- Asynchronous Messages. This criteria addresses the issue of how well the protocol supports allowing nodes on the data bus to transmit a message whose time of transmission is not known apriori. This criteria is also a measure of how well the protocol supports the transmission of priority messages requiring immediate access to the bus.

Cost/Complexity. Evaluation of protocol against this criteria should take into account nonrecurring and recurring cost areas. This should include, as a minimum, hardware development costs, hardware fabrication costs, and software/firmware costs. Issues to take into consideration in this area may include availability of hardware, firmware and software from commercial sources as opposed to new development in each of these areas. For a standard approach to this area, cost will be considered to be a function of nonrecurring costs plus a fixed number of units times recurring costs.

- Non-recurring Hardware and Software Costs. The cost/complexity of development of the hardware and software necessary to support the protocol.

- Recurring Hardware and Software Costs. Cost/Complexity of elements in production after development.

- Support Costs. Cost to support these elements once in the field.

- Weight, Size, Power. Physical requirements of the data bus elements.

4. Protocols: A number of protocols were researched in the literature, the following list organized by categories were investigated:

Fixed Assignment

Time Division Multiple Access (TDMA)
Frequency Division Multiple Access (FDMA)

Random Assignment

Aloha
Carrier Sense Multiple Access (CSMA)
Carrier Sense Multiple Access with collision detection (CSMA/CD)

Controlled Assignment

Central Control

Global Scheduling Multiple Access (GSMA)
Roll Call Polling
Split-Channel Reservation Multiple Access (SRMA)

Distributed Control

Priority Assignment
Broadcast Recognising Access Mode (BRAM)
Assigned Slot Listen-Before-Talk
Distributed Scheduling Multiple Access (DSMA)
Token Ring
Token Passing
Fast Information Transfer System (FITS) (n.b. FITS is an enhanced 1553-type bus with more flexible addressing, versatile message formatting and control capability)

In order to reduce superfluous analyses, the above list of protocols was initially filtered based on efficiency/data latency. Assumptions associated with this filtering process were minimum acceptable bus efficiencies of 50%-60% and maximum data latencies not exceeding 2-3 normalised packet transmission times. Since much of the specific system implementation aspects of these protocols has not been completed, the protocols were treated as generic types.

There were six protocols which were found to meet this initial set of factors:

1. Broadcast Recognising Access Mode (BRAM).
2. Carrier Sense Multiple Access/collision detection (CSMA/CD).
3. Distributed Scheduling Multiple Access (DSMA).
4. Fast Information Transfer System (FITS).
5. Split-Channel Reservation Multiple Access (SRMA).
6. Token Passing (Logical Ring).

Of these six, only three had sufficient information available to produce a meaningful analysis. These three were then the subject of the more detailed analysis described below.

1. CSMA/CD.
2. FITS.
3. Token Passing.

5. Evaluation Method. The first step in the evaluation process was to subjectively compare each of the seven major criteria against each other (paired comparisons), reference Figure 1A. Through this comparison, a weighting value was obtained for each criteria. In order to gain additional analysis insight, within each major criteria the sub-criteria were similarly compared, reference Figure 1B. Each protocol was then evaluated against each criteria - these evaluations were subjective and considered scientific and engineering judgement, based on numerous years of system integration/architecture/protocol experience. Upon completion of these evaluations, two methods of decision making were applied:

1. Linear Additive Method.
2. Maxi Min Principle.

Under the Linear Additive Method, the subjective judgement for each protocol was multiplied by the weighting factor for each criteria and then added together to determine the total value for each alternative protocol. The largest absolute value was considered to be the choice.

$$C\ (a_i) = \Sigma\ w_j\ x_{ij}$$

Under the Maxi Min approach the weighting value and the judgement factor were combined for each alternative for all criteria. These values were then placed into a decision matrix where the maxi min principle was applied. In essence, the minimum value (regardless of the criteria) for each alternative was identified and from these minimums the maximum value was identified as the choice. The alternative with the maximum minimum value was considered the choice because of the least risk.

$$\max_i \min_j C\ (\theta_{ij})$$

6. Results of Evaluation: The weighting of the subcriteria and criteria was performed with the results shown in Table 1.

TABLE 1 - WEIGHTED VALUE

.061 - Throughput/Response
  .167 - Effective link level data throughput
  .833 - Data Latency

.060 - Message Structure
  .146 - Addressing Capacity
  .372 - Broadcase Capability
  .205 - Block Size
  .277 - Content Addressing

.272 - System Integrity
  .119 - Monitorable
  .447 - Testable
  .058 - Initialization
  .376 - Data link assurance of receipt

.382 - Fault Tolerance
  .389 - Fault Detection
  .125 - Fault Containment
  .040 - Fault Isolation
  .446 - Recovery Reconfiguration

.064 - Adaptiveness
  .342 - Incorporation of New Technology
  .081 - Compatible with old mechanisms
  .577 - Parameterization Capability

.123 - Flexible Network Control Strategy
  .094 - Central Control
  .567 - Distributed Control
  .136 - Synchronous
  .203 - Asynchronous

.038 - Cost/Complexity
  .100 - Non-recurring Hardware and Software costs
  .137 - Recurring Hardware and Software costs
  .400 - Support Costs
  .363 - Weight, Size, Power

As a measure of the integrity of the weighted comparison process an index for the consistency of the judgements was derived. This measure should be less than 1.0 if the judgements are consistent. Values greater than 2.0 suggest that perhaps the process should be repeated with more attention paid to each judgement. For the value of Table 1, the consistency value is .2276 -- highly consistent.

In the second step each protocol was then evaluated against each sub-criteria by assigning values ranging between 0 and 1 - a large number always indicating "more" of an attribute. Sub-criteria weighted values (1st step) were then multiplied by their assigned values (2nd step) and summed to provide the major criteria values. The results are indicated in Table 2.

TABLE 2 - PROTOCOL EVALUATIONS

	CSMA	FITS	Token Passing
Throughput/Response	.767	.549	.467
- Effective link level data throughput	.6	.8	.8
- Data Latency	.8	.5	.4
Message Structure	.883	.770	.786
- Addressing Capacity	1	.7	.9
- Broadcast Capability	1	1	1
- Size (Block	.7	.9	.7
- Addressing (Content)	.8	.4	.5
System Integrity	.346	1	.846
- Monitorable	.6	1	1
- Testable	.2	1	1
- Initialization	.6	1	.3
- Data link assurance of receipt	.4	1	.7
Fault Tolerance	.784	.768	.739
- Fault Detection	1	.8	.8
- Fault Containment	.5	.9	.7
- Fault Isolation	.5	.8	.7
- Recovery Reconfiguration	.7	.7	.7
Adaptiveness	.824	.774	.594
- Incorporation of New Technology	.7	.7	.7
- Compatible with old mechanisms	.1	.9	.1
- Parameterization Capability	1	.8	.6
Flexible Network Control Strategy	.857	.769	.668
- Central Control	.2	1	.5
- Distributed Control	1	.7	.7
- Synchronous	.5	1	.9
- Asynchronous	1	.7	.5
Cost/Complexity	.634	.81	.733
- Non-recurring Hardware & Software costs	.8	.5	.4
- Recurring Hardware & software costs	.7	.8	.6
- Support Costs	.6	.9	.8
- Weight, Size, Power	.6	.8	.8

Using the Linear Additive approach, the weighting factor was applied to each criteria factor and the total summed for each alternative. The results are shown below:

CSMA/CD	.676
FITS	.820
Token Passing	.737

The largest number indicates the alternative which best satisfies all criteria - FITS.

Using the Maxi Min decision principle, a matrix of the combinatorial product for each criteria against the alternative protocols is first formed:

CRITERIA	CSMA/CD	FITS	TOKEN PASSING
Throughput	.893	.776	.724
Message Structure	.949	.896	.904
System Integrity	.133	1	.728
Fault Tolerance	.522	.[illegible]94	.445
Adaptiveness	.917	.89[illegible]	.792
Control Strategy	.875	.79	.705
Cost/Complexity	.885	.945	.920

From this the minimum value in each column (alternative) of the matrix is chosen.

	MINIMUM	MAXIMUM
CSMA/CD	.133	
FITS	.494	.494
Token Passing	.445	

The maximum of the minimums is the choice because this represents the alternative with the least risk.

FITS with a .494 value

In retrospect, the selection of a high speed 1553B-type (FITS) bus has many inherent attendant advantages. Included are such intangibles as (1) broad experience data base, (2) general user acceptability, (3) availability of design/support tools and (4) established implementation guidelines.

7. SUMMARY: This analysis is indicative of a logical approach to accomplish the selection of a high speed data bus. There is subjective, scientific judgement involved in the choice of:

1. weighting criteria
2. relative weighting
3. protocol vs. criteria judgement

However, the results of this analysis will be presented to the AE9B sub-committee on data bussing. It is hoped, that these judgements will be refined and an agreeable set of criteria determined. Once this is accomplished, candidate bus protocols can be evaluated in a systematic manner and an impartial standardized bus can be defined.

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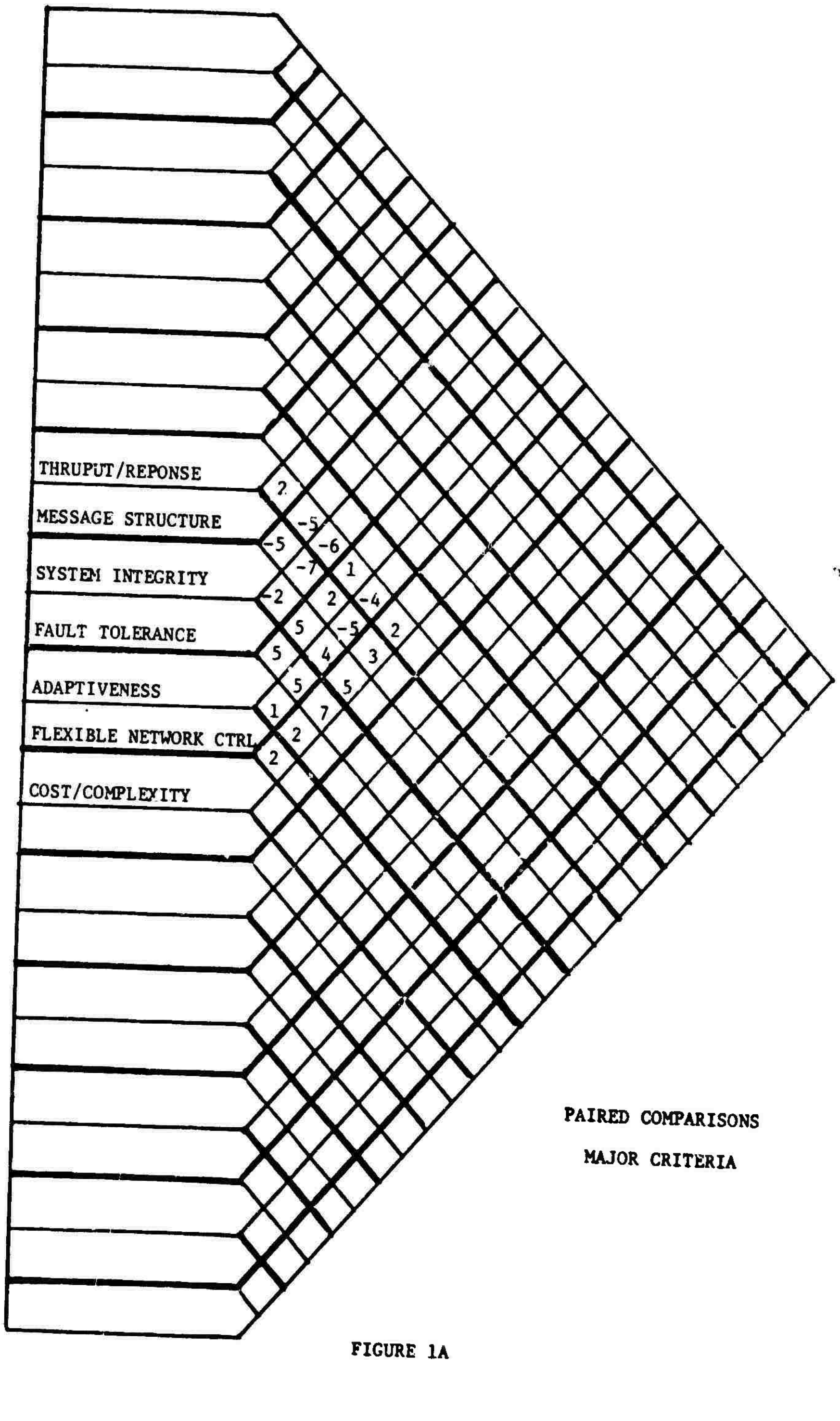
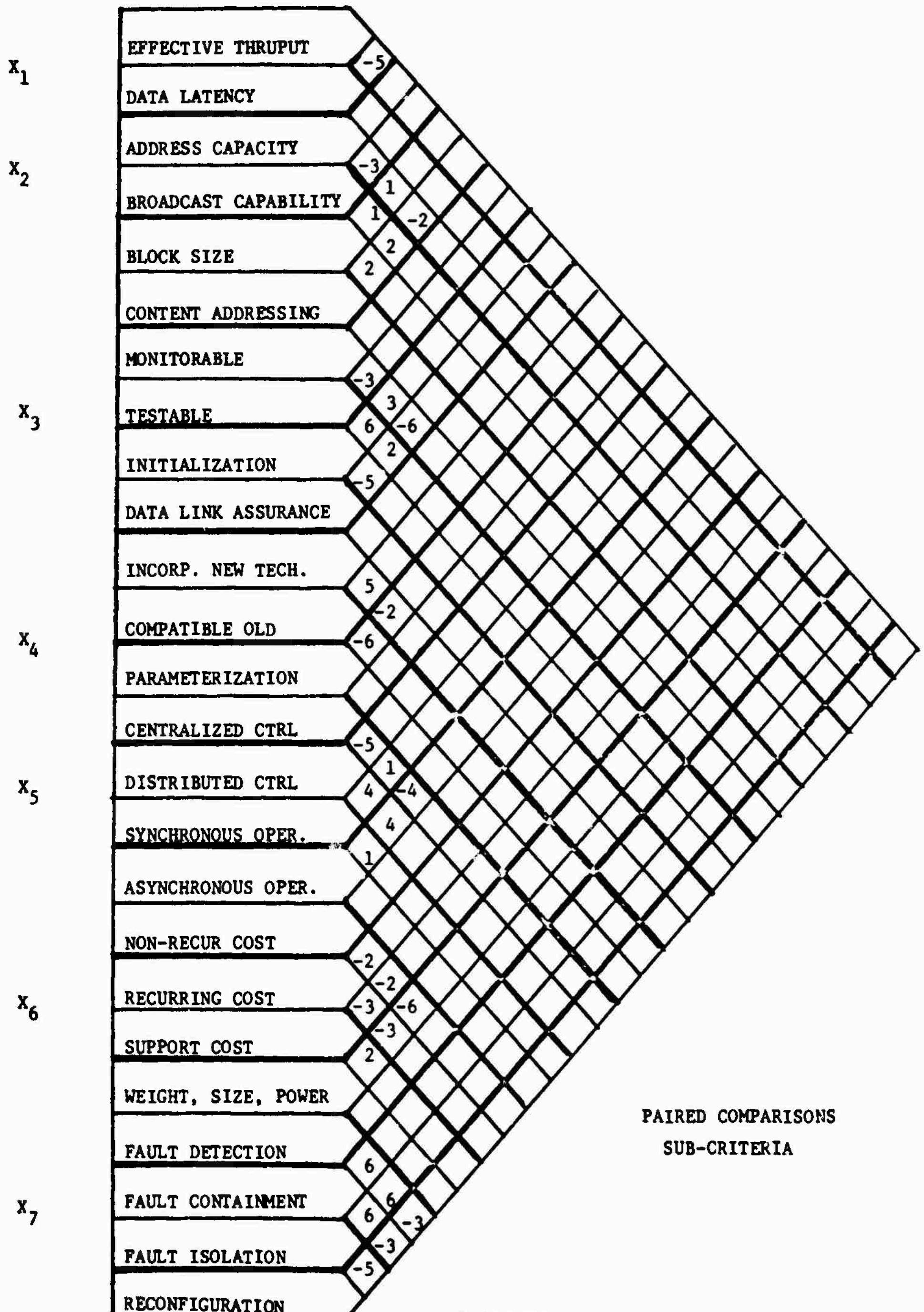


PAIRED COMPARISONS

MAJOR CRITERIA

FIGURE 1A



PAIRED COMPARISONS
SUB-CRITERIA

FIGURE 1B

DISCUSSION

F.W.Broecker, Ge

How do you propose to decide in the paired comparison process what figure should be given? What are the evaluation criteria?

Author's Reply

At this time, the figure given is determined through subjective judgement. However, there is consideration being given for using paired comparison against each of the protocols as well as each of the evaluation criteria in the separate categories.

W.H.McKinlay, UK

It would be interesting to know whether the original inputs to this work (the overall system concept, factors to be considered, etc.) were objective; results of studies or actual experiment, or subjective; opinion or general beliefs about future systems. The method itself is precise and therefore the quality of the inputs matters.

Author's Reply

The final inputs for this analysis will be determined by the SAE/AE9B committee on high speed data busing. The initial inputs were determined by various US Air Force contractual efforts as well as an Air Force panel of experts.

M.Burford, UK

Having proposed a screening mechanism to aid network selection and illustrated it with an example, have you had a chance to establish the sensitivity of the mechanism to an erroneous weighting for a particular or group of attributes?

Author's Reply

There is a consistency measurement taken to assure that a weighting relative to one factor is consistent with the relationship to the other factors.

AVIONICS FAULT TREE ANALYZER

Michael E. Harris
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SUMMARY

The

The long awaited era of reliable self-diagnosing avionics is at hand. Due to recent technological advances in microcomputing and large scale integration ~~(LSI)~~, overhead cost of flying avionics support functions have been minimized. ~~McDonnell Douglas's~~ F/A-18 aircraft allows use of a man-portable, microprocessor-controlled, ground-based test set to isolate avionic failures to the electronic card or shop replaceable assembly (SRA). Through a single existing connector on the aircraft, this Avionics Fault Tree Analyzer (AFTA) communicates, exercises, interrogates, and diagnoses the Avionic subsystems. There are many instances when the AFTA not only isolates faults in the electronics but also in the aircraft wiring. Largely due to the truly distributive processing architecture of the aircraft and the modular design of the avionics, fault detection and isolation well beyond the Weapon Replaceable Assembly (WRA) is achieved within milliseconds. Avionics as sophisticated as the Flight Control System, RADAR, and the Stores Management System are supported quickly and efficiently with electronics card replacement without intermediate level ground support facilities. The AFTA is currently a ground based device; ~~however,~~ the AFTA function will be incorporated in future aircraft.

Although

The required hardware for an AFTA already exists in contemporary aircraft. AFTA is composed of a general purpose microcomputer with two input/output interfaces. The human interface uses a plasma display and touch panel to reduce weight and increase ease of operation. The aircraft's multipurpose displays and associated programmable menu switches would satisfy this function. The aircraft interface is a derivative of MIL-STD-1553 avionics multiplex bus.

Increasing density of computer memory, more modular designed avionics, and the use of very large scale integrated (VLSI) devices will allow future aircraft to fly with the AFTA function. Ramifications include minimizing the need for intermediate avionic repair facilities, increased aircraft operational readiness, a decrease in aircraft recurring cost, and a reduction in spares investment.

INTRODUCTION

Since 1950 up through 1970, avionics systems were designed primarily with one goal in mind. That is, to satisfy mission operational requirements. Little or no consideration could be afforded at the front end of the design cycle to support an ease-of-maintenance concept for these systems. Consequently, the support task was performed using a brute force philosophy as evidenced by the physical size and extended test times of the Ground Support Equipment (GSE). During the same time, however, revolutionary changes were taking place in the electronics industry, particularly in silicon technology. These changes were of such dynamism as to literally run away from effective avionics applications engineering. Fortunately, today's engineers have caught up with these advances and are beginning to develop avionic systems that do in fact afford consideration to their support as well as meeting demanding operational requirements. Today's avionics are modular to the electronic card level, and, more significantly, the systems are acquiring a reliable self-test facility.

In just the past few years, the importance of this self-testing facility has increased in direct proportion to the maintenance cost of the avionics equipment. With the incorporation of very large scale integration (VLSI) electronics, the built-in-test (BIT) function contributes less performance overhead than in the past. An heuristic conclusion is that the more effective the BIT, the less sophisticated the GSE requirement. There is still a real estate trade-off between BIT and performance both in hardware and software. However, due to maintenance economics, the VLSI circuitry, and the ingenuity of the contemporary engineer, the penalty of extensive BIT is not severe.

The McDonnell Douglas F/A-18 aircraft is an example of a transitional product derived from the changing technology. The F/A-18 is a software intensive, digital aircraft. Its avionic system architecture is composed of two "mission computers" and over two dozen subsystems whose well defined tasks are controlled by the mission computers through a central communication bus. Each of the avionic subsystems are computer based and decoupled from one another except via digital bus communication. The subsystem's BIT requirements included fault isolation to the weapon replaceable assembly (WRA, i.e., black box) for 98% of the faults. The contractor-furnished subsystems were modularly designed such that, although not a contractual requirement, the BIT could be used to isolate faults to the electronic card within the WRA. This electronic card assembly is usually referred to as a shop replaceable assembly (SRA). The modular design and extensive subsystem BIT became the foundation for a suitcase-sized tester called the Avionics Fault Tree Analyzer (AFTA).

The AFTA is a microprocessor based, general purpose computer designed to execute fault isolation programs. These programs, one for each WRA or system to be tested, are commonly referred to as Fault Trees. It is these Fault Tree programs that direct the processing necessary to achieve effective fault isolation.

During the extensive flight development testing of the F/A-18, a team of avionics engineers evaluated and maintained the aircraft avionics without sophisticated GSE. Their tools were the aircraft BIT, the ability to interrogate the subsystem's memory by using on-board memory inspect, and their knowledge and experience of the avionics they designed and integrated. With AFTA, it is now possible to store the accumulated knowledge of these avionic engineers for the purpose of fault isolation to the SRA level. The AFTA is programmed to automatically perform the same type tests and logical analysis that an engineer with several years of F/A-18 maintenance experience would perform. Since the Fault Tree programs are developed by the same engineers who designed, integrated, and supported the F/A-18 avionics during development, it takes advantage of the combined talents and experience of a formidable group of experts. Once developed and programmed, simple reproduction of the AFTA hardware and software makes these combined talents and experience available to any AFTA user. Figure 1 illustrates the use of the AFTA at the aircraft. The resident aircraft built-in-test will isolate to the WRA. The AFTA will be connected to the aircraft for both power and communication. AFTA will isolate to the SRA and/or the aircraft wiring, informing the maintenance crew of its findings. The defective WRA will be removed from the aircraft and the defective SRA replaced in a sheltered area. The repaired WRA is determined ready for issue (RFI) by re-running the AFTA program or successfully performing the aircraft built-in-test. The entire repair sequence is estimated to consume less than 30 minutes.

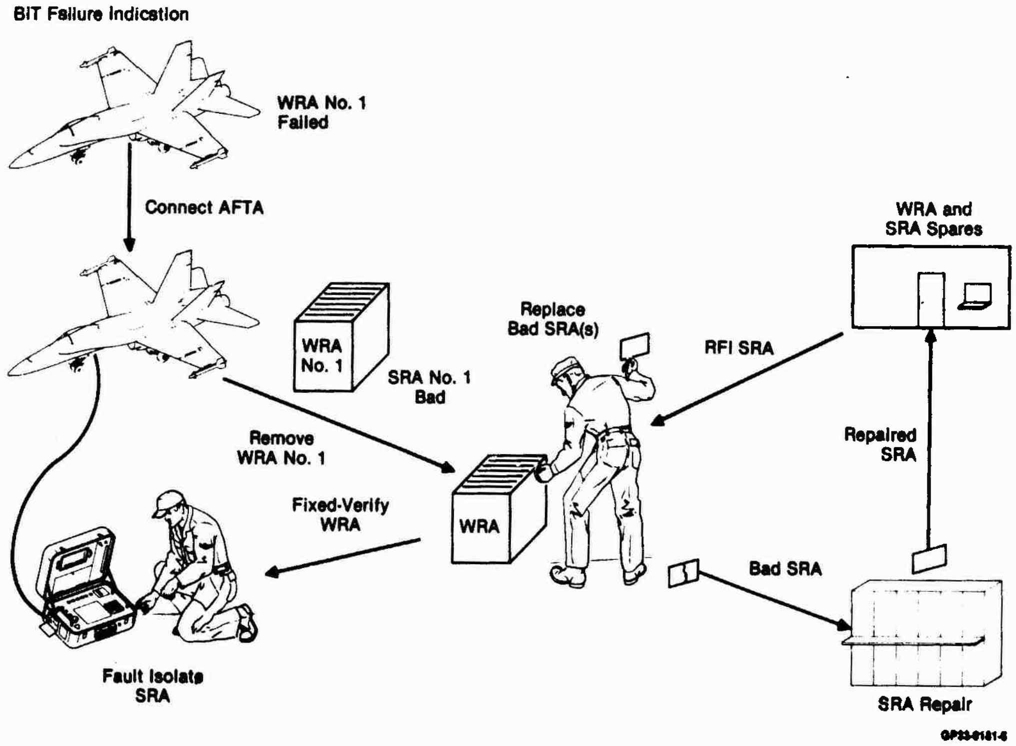

FIGURE 1
AFTA USAGE

AFTA MECHANIZATION

With the advent of the microprocessor and other large scale integrated (LSI) electronic components, the text book design of a truly distributive and efficient computer architecture for aircraft control became feasible. The F/A-18 is a practical implementation of this concept. The F/A-18 has a higher percentage of software controlled electronics than any other existing aircraft. Due to VLSI electronics, it is possible and desirable to distribute the avionic tasks to subsystems coupled by a common communication bus structure. Each subsystem controls its functions by its dedicated processor(s). The subsystem reports or controls its processes under the direction of a master processing unit which communicates with all of the subsystems. In the F/A-18 aircraft, this master processing unit is a pair of Mission Computers. The communication link is a Manchester encoded serial bus designed around the MIL-STD-1553B. Although not a requirement, the two underlying concepts of LSI and extensive software control forced modular designs within the avionic subsystem. The many tasks a subsystem was responsible for were designed in modular form (an electronic card). The AFTA concept is based upon modular designed avionic subsystems and a common communication bus between the subsystems. Figure 2 is a simplistic representation of the F/A-18 avionics system and the Avionics Fault Tree Analyzer. The AFTA hardware requirements are a communication link compatible with the avionics and a computer to test and control the subsystems.

The AFTA must be physically small and capable of controlling the avionics in real time. Because the AFTA is to be used at the aircraft, and aircraft down time must always be minimized, the AFTA must be easily moved to and connected to the aircraft. The AFTA receives its power and avionics miltiplex bus interface through two existing aircraft connectors in the F/A-18's nose wheel well. The AFTA requirements of light weight and short test times have been accomplished as a result of the current LSI technology and extensive avionics software. Figure 3 is a photograph of the Prototype AFTA. The prototype AFTA is itself a distributed processing test system. A simplified block diagram of the AFTA is presented in Figure 4. The main processing unit (MPU) is a microprocessor based, single board computer with basic instruction cycle of 8.24×10^{-7} seconds. AFTA includes 96,000 8-bit bytes of read only memory containing the operating systems, 48 programmable parallel discretes, and a serial communication circuit to control MPU peripherals.

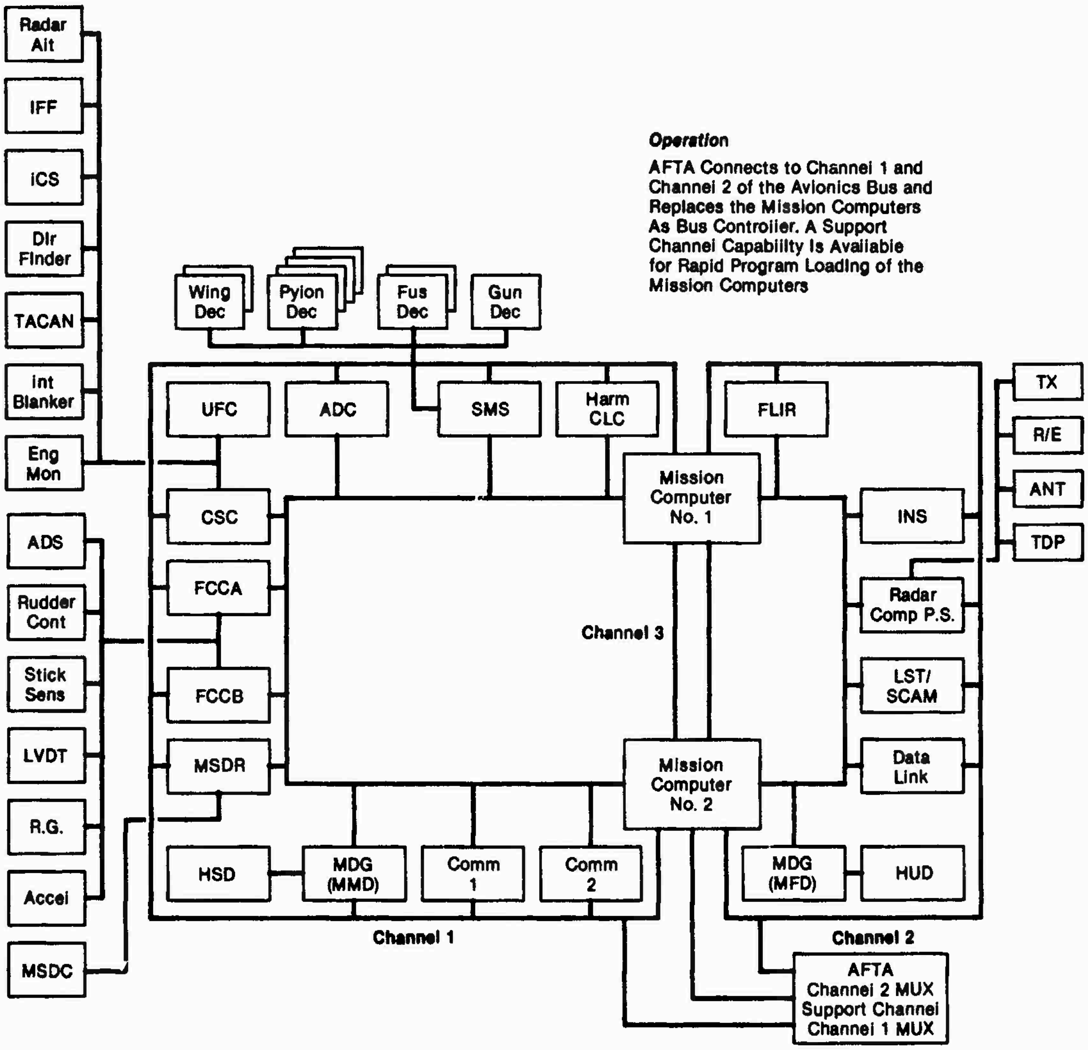

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FIGURE 2
AFTA - AVIONICS IMPLEMENTATION

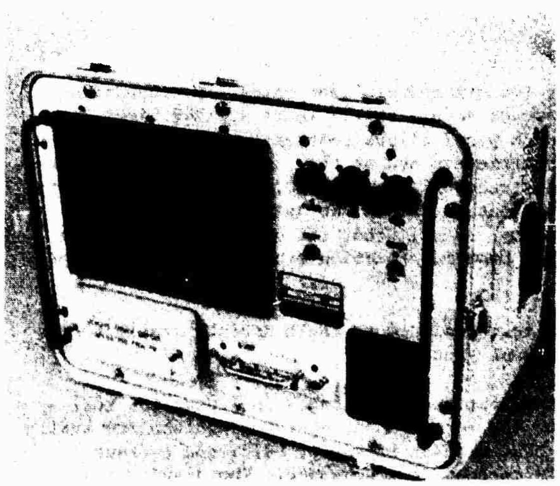

FIGURE 3

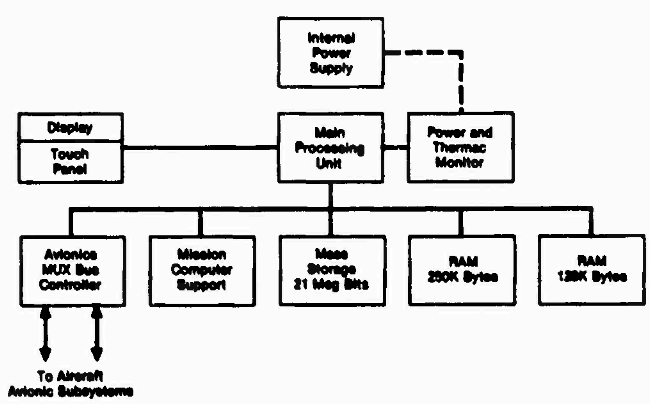

FIGURE 4
AFTA BLOCK DIAGRAM

AFTA-Avionics communication is accomplished by a single microprocessor controlled MIL-STD-1553B communication controller called the Avionic Multiplex Bus (AVMUX) controller. The AVMUX controller converts the message stored in common memory to the biphase Manchester encoded signal required of the avionics. Figure 5 diagrams the signal characteristics.

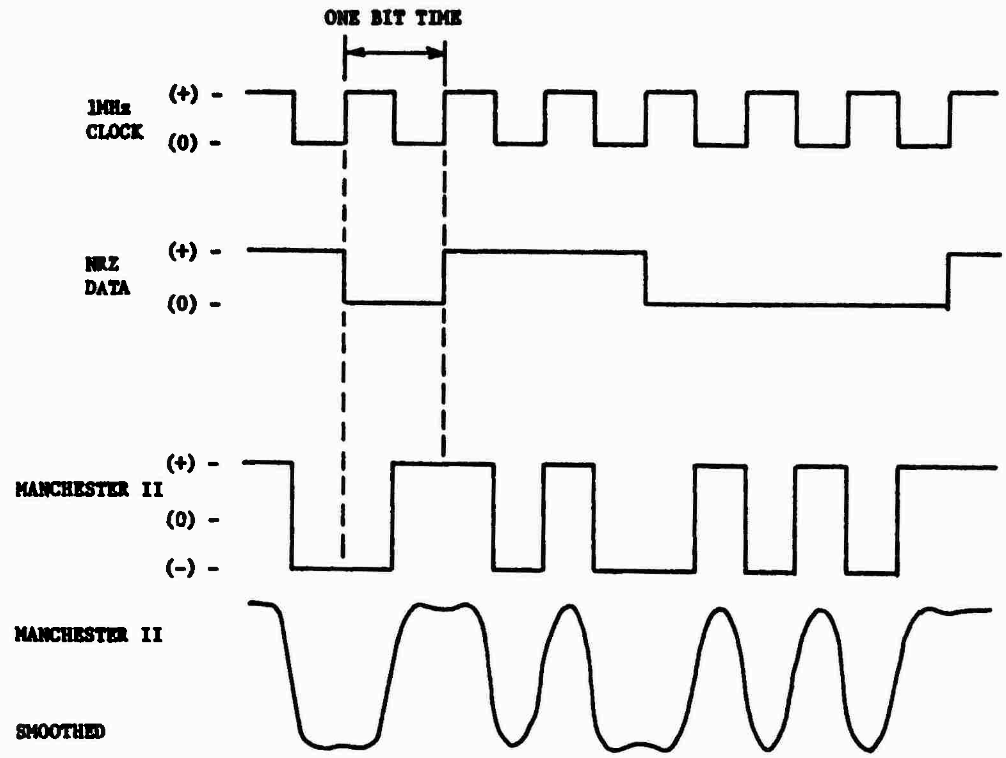

FIGURE 5 DATA ENCODING

The operator control is accomplished through a neon display and an infrared touch panel. The neon display is rugged, light weight and readily interfaced to a microprocessor based MPU. Displaying up to 480 alphanumeric characters on a 4 x 8 inch front, this operator input/output device receives operator inputs or displays test results. The display features twelve (12) rows, forty (40) columns, weighs 10 lbs, and can withstand a fifteen (15) G shock.

Attached to the face plate of the display is an infrared (optical) light grid. This light grid is the operator's main input media. The AFTA will display an operator action and offer options in the form of an underlined (scored) choice such as:

DO YOU WISH TO CONTINUE?

<u>YES</u> <u>NO</u>

The operator will touch the appropriate selection disrupting two orthogonal light beams. Corresponding coordinates are sent to the MPU and the computer program responds accordingly. There are 240 light intersections in the 4 x 8 inch display area. The display and touch panel allows software programmable "switches", thereby reducing front panel spatial and weight parameters and at the same time increases its versatility. In addition, the operator need not relate an instruction (or desire) from the display media to dexterous motion such as typing. He will read the instructions and touch the option. Figures 6 through 11 portray a typical sequence of events from the display. Recall that the underlined words are the only valid responses for that particular display. A light beam intersection broken at any not underlined area will be ignored by the MPU.

Upon application of power, the AFTA will perform a self test designed to fault isolate itself to the SRA. In many instances, the fault isolation extends to component groups.

All displays are standardized. The first line is reserved for system messages including the real time, date, Julian date, day, and current display option. On the second line, operator options are available if applicable. The operator may select a program from BUBBLE (bulk storage), PRINT the current display, go to NEXT display, change number base, or ABORT the current test sequence. The display area below the broken line is used for menus or is available to the WRA fault tree designer for presenting operator instructions, test results, etc. At turn-on, after successful completion of the AFTA self test, the top level menu is displayed as in Figure 6. A brief description of each option follows:

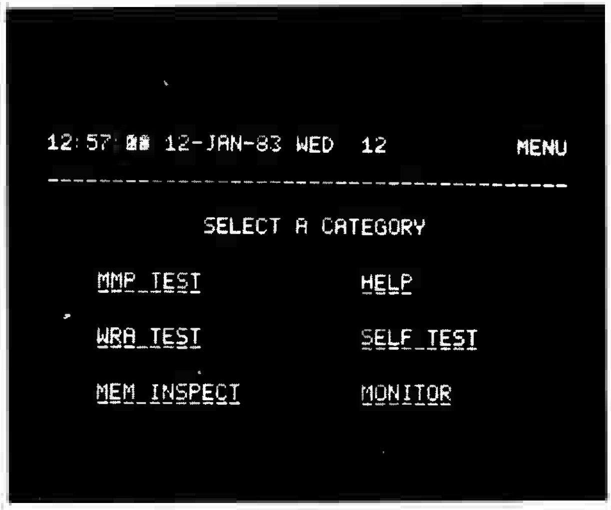

FIGURE 6

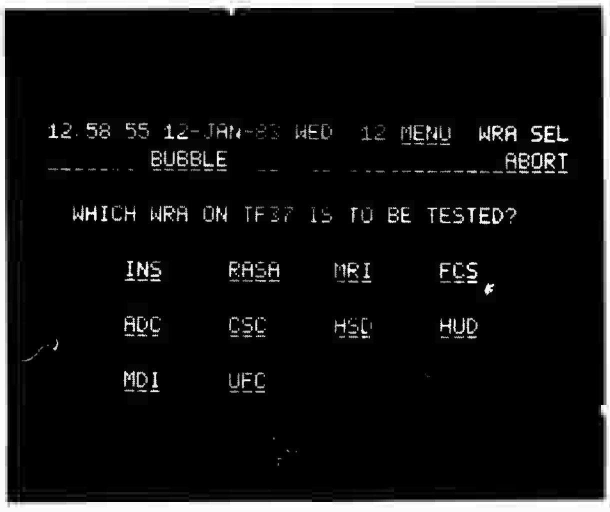

FIGURE 7

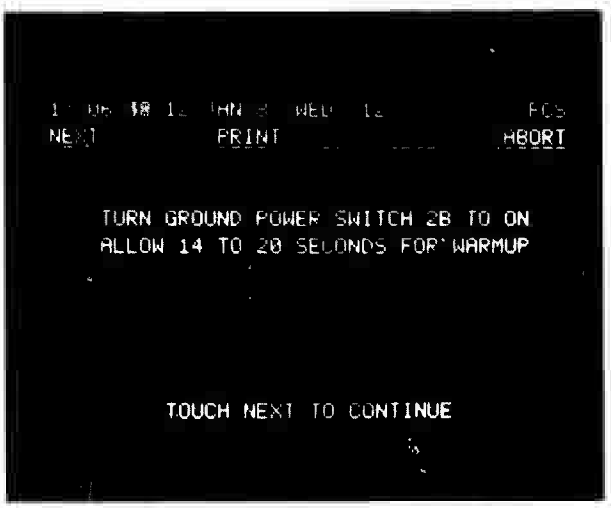

FIGURE 8

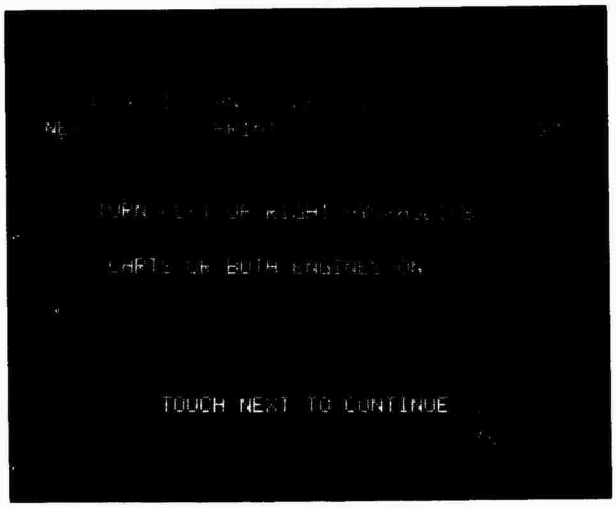

FIGURE 9

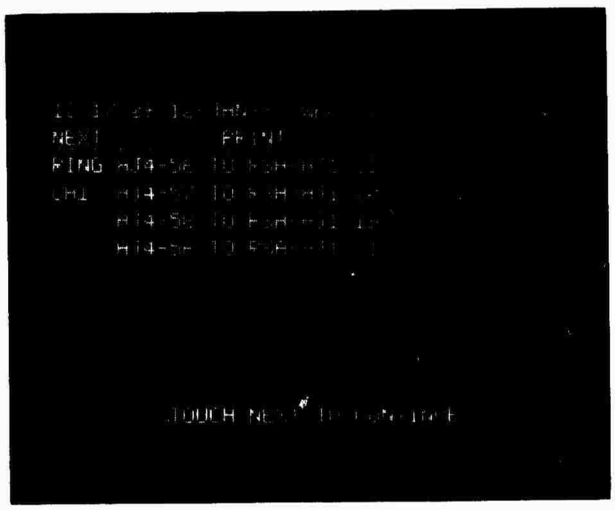

FIGURE 10

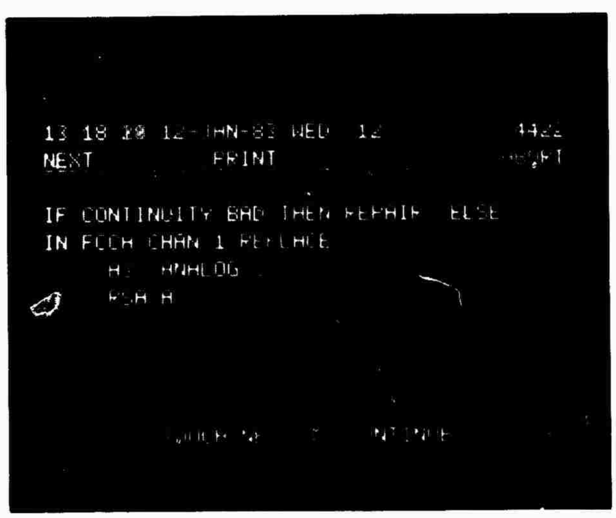

FIGURE 11

MMP TEST: The aircraft's Maintenance Monitor Panel (MMP), located in the nose wheel well, will display a number corresponding to a defective WRA as determined by the aircraft's self test. Selecting the AFTA menu option MMP TEST will allow the maintenance crew to enter the MMP code into AFTA. AFTA will then execute the appropriate fault tree program to confirm the WRA failure and fault isolate to the SRA.

WRA TEST: Upon this selection, the next display will be Figure 7 comprising a list of WRA's to be fault isolated. Figure 7 is not the entire list of fault trees, but is included here for discussion purposes only.

MEM INSPECT: Memory inspection into the WRA under test is performed automatically by the fault tree program. The MEM INSPECT selection will, however, allow manual interrogation in four number bases: octal, hexidecimal, binary, and decimal.

HELP: The AFTA is designed to fault isolate the F/A-18 with little or no training on the use of AFTA. However, upon selecting HELP, several pages of information are displayed educating the operator on the use of AFTA and the maintneance of the aircraft.

SELF TEST: As mentioned previously, upon power initiation, the AFTA will perform a self test. An operator initiated self test is also available. After selection, a submenu is displayed allowing the operator to select portions of the AFTA to be investigated.

MONITOR: This option is included in the preproduction models only. The MONITOR option is password controlled and allows such engineering evaluations as change register, modify AFTA memory, and break point insertion.

As indicated earlier, Figure 7 is a result of touching WRA TEST on the top level menu of Figure 6. The display of Figure 7 is incomplete. The following lists the WRA's fault isolated to the electronic module (SRA):

HEAD UP Display (HUD)	Gun Decoder (GD)
Multipurpose Display Indicators (MDI)	Wing Decoder (WD)
Multipurpose Display Repeater Indicator (MDRI)	Pylon Decoder (PD)
Maintenance Signal Data Recorder (MSDR)	Fuselage Decoder (FD)
Maintenance Signal Data Converter (MSDC)	Up Front Control (UFC)
Communication Set Control (CSC)	Mission Computer (MC)
Horizontal Situation Display (HSD)	RADAR Transmitter
Inertial Navigation System (INS)	RADAR Data Processor
UHF/VHF Communication Set (Comm 1, 2)	RADAR Receiver Exciter
Data Link (DL)	RADAR Antenna System
Engine Monitor Display (EMD)	Flight Control Computer (FCC)
Stores Management Processor (SMP)	Air Data Computer
Linear Electrical Accelerometer	Rate Gyroscope

This list of WRA's is portrayed on several AFTA display pages. The operator selected "NEXT" to change pages.

After selecting the Flight Control System (FCS) fault tree programs, the AFTA will instruct the operator to turn FCS power on. The operator's next evolution will be to ensure there is sufficient hydraulic energy to thoroughly test the FCS. Upon connecting the hydraulic carts or turning on both engines, the operator will touch NEXT to commence FCS testing. Less than three minutes later, the AFTA will display the defective SRA, or, as in the example of Figure 10, further instructions are given to measure aircraft wire continuity. Figure 11 informs the operator of the results of the FCS fault diagnostics.

The AFTA software is partitioned into the real time operating system used to control the AFTA hardware and the application software for avionics fault isolation.

The key to any modern portable, real time computing system is the reduction of overhead; thereby forcing a small and efficient operating system. The AFTA operating system is designed around the classical hierarchical machine depicted in Figure 12. The kernel is composed of the modules of the system that reside within the machine, as opposed to those that operate as process layers. The kernel has responsibility for processor management, memory management, device assignments, and file management. A short description of each process group follows:

- Command Interpreter - The purpose of this process is to identify an operator request and to determine and activate the appropriate task to act on that request.

- Fault Tree Application Processes 1-N - These "jobs" are not part of the operating system but are the vehicle by which the avionics is fault isolated. They will be discussed in detail later in this paper.

- AFTA Self Test - The purpose of this process is to test the AFTA hardware, e.g., tape interface, RAM and ROM for faults and to inform the operator of the faults detected.

- Memory Inspect Process - The purpose of this process is to validate, request from Memroy Inspect Utility, and output to the Display Manager via the Kernel the contents of an operator selected address in an operator selected avionic subsystem.

- Initialize Process - The purpose of this process is to set the operating system of the AFTA to an initial state from which processing of any subsequent AFTA function will commence.

- System Integrity Check Process - The purpose of this process is to interrogate all avionic subsystems interfaced with the AVIONICS MUX BUS for status. This process interfaces with the AVIONICS MUX BUS process.

- Mission Support Process - The purpose of this process is to enable operator development support and control of the F/A-18 Mission Computers from non-avionics mux bus channels. This process will directly control dedicated hardware. In this respect, this process is more accurately referred to as a driver.

- Memory Load/Verify Process - The purpose of this process is to enable loading programs into selected avionic processors interfaced with the AVIONICS MUX or Mission Computer support channel. It shall additionally enable the download of selected WRA's operational flight programs to mass store for laboratory evaluation.

- Mass Storage Control Process - The purpose of this process is both to provide the user facility for transfer of data to and from the mass storage media and to control the transfer of that data.

- Avionics Mux Bus Process - The purpose of this process is to control access to/from avionic processors connected via the AVIONICS MUX BUS. This process also interfaces directly with the AFTA AVIONICS MUX BUS hardware.

- Display Process - This process is to control the input to and output from the plasma display/touch panel. It shall determine valid key depressions and which task shall receive notification of a key depression. This process controls the display of pages of text, system status messages, menus, control keys, and the contents of avionics memory.

- Key Process - The purpose of this process is to accept operator input in the form of key depressions from the display and inform the Display Process of those key depressions.

- Printer Process - The purpose of this process is to control the printing of the contents of the display screen to an external printer. This process will also act as the printer driver controlling the transfer of data and issuing commands to the external printer.

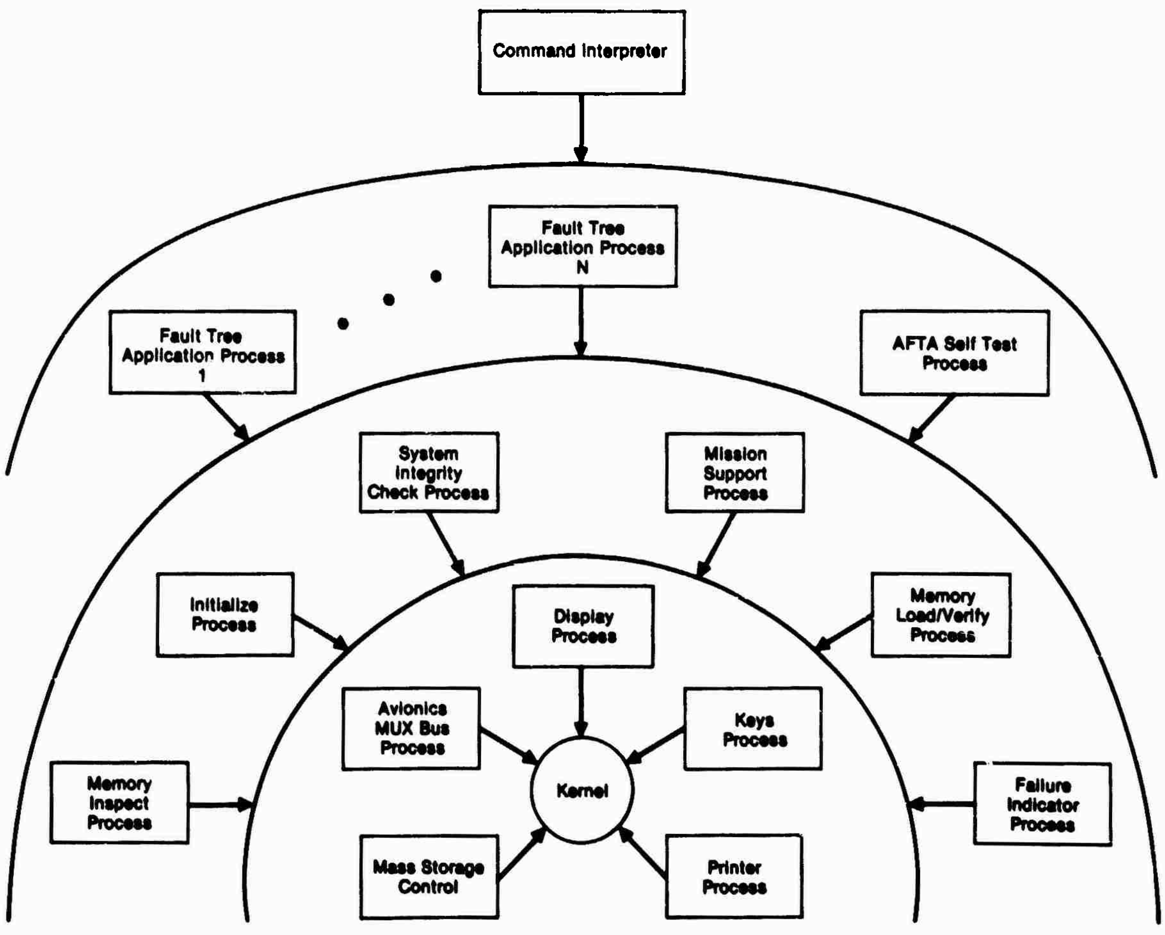

FIGURE 12
AFTA OPERATING SYSTEM

Except for the nucleus (kernel), the processes are coded in a high level, inherently structured, programming language. Each task is composed of one or more modules of 200 lines or less. The modules are described by Nassi-Schneiderman Charts to ensure a structured style.

Due to the comprehensive nature of the F/A-18 BIT and its integrated system architecture, this suitcase-sized tester can support the aircraft without the expense of the typical intermediate level maintenance facility. The essence of the AFTA is the fault tree. A fault tree is in flow diagram format and it illustrates the procedures necessary to fault isolate to the electronic card. As stated previously, the effectiveness of the fault trees to isolate a WRA failure to the SRA level is highly dependent on the avionics design. The McDonnell Aircraft requirement that BIT detect and isolate (to the WRA) 98% of the faults with a 99% confidence caused most of the F/A-18 equipment designers to develop an architecture allowing fault isolation to the SRA group. The aircraft system design incorporates a central (and redundant) bus for inter-computer communication. Each serial bus is operated in a half-duplex fashion using the Manchester encoding format. The two mission computers are bus masters. All communication with the avionic subsystems is through the Mission Computers using this Manchester bus (Avionics Multiplex Bus). The Avionics Multiplex Bus is therefore an information window into the avionic subsystem. The AFTA replaces the Mission Computers as the bus master and communicates directly with the subsystem. The AFTA has the capability of inspecting the internal memories of the avionics and controlling the avionics to the same extent as the Mission Computers. It is the avionic BIT effectiveness, the logical evaluation of the results, and inspection of the internal memories of the avionics that make up the avionic fault trees. Most of the F/A-18 avionics can be fault isolated to the SRA with only these tools. Some WRA's require more imaginative efforts.

Some avionic equipments are designed to take advantage of the existence of the processor and its non-volatile memory which was included as part of their functional design. In these instances, the operational program is removed and a diagnostic routine is loaded in its place. In such a scenario, the AFTA is programmed to load the diagnostic routines, fault isolate to the SRA level, and to reload the operational program in the WRA while installed in the aircraft. A third method for fault isolation employs less deterministic methods.

A few of the subsystems are not directly connected to the avionics multiplex bus, making the fault tree philosophies mentioned less effective. For these systems, the fault tree designer's experience has a more predominent role. In many of these equipments, an analysis of the functional (or mal-functioning) inputs and outputs based on a thorough knowledge of the WRA mechanization allows logical conclusions to be drawn as to which SRA is at fault. The AFTA is loaded with the necessary system information and programmed to perform this logic function.

These fault isolation methods are illustrated in Figure 13. The AFTA is programmed to automatically perform the same type tests and the logical analysis an engineer with several years of F/A-18 development experience would perform manually. This is the foundation of the fault trees. Since the AFTA's fault trees are developed and verified by the same engineers who designed, integrated, and supported the F/A-18 avionics through development and into production, it takes advantage of the combined talents and experience of not only the McDonnell Aircraft experts but also the equipment designers. Figure 14 is an abbreviated fault tree example. As can be seen from the example, the fault isolation effectiveness is not perfect. There exist SRA interdependencies within most of the avionics forcing unwanted ambiquity groups.

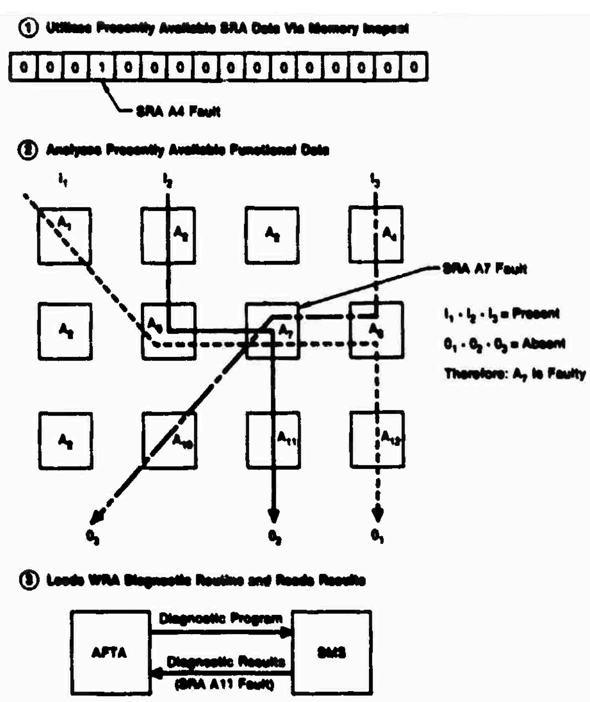

FIGURE 13
AFTA FAULT ISOLATION METHODS

As illustrated in Figure 14, the AFTA will initiate the WRA BIT by using the AVMUX. If the WRA does not respond, the appropriate SRA's are determined defective. When WRA BIT completes, the AFTA will automatically memory inspect selected WRA addresses. The contents of these addresses relate to SRA(s) or alternate operator instructions. The actual fault tree for the Air Data Computer contains over 100 such decision blocks.

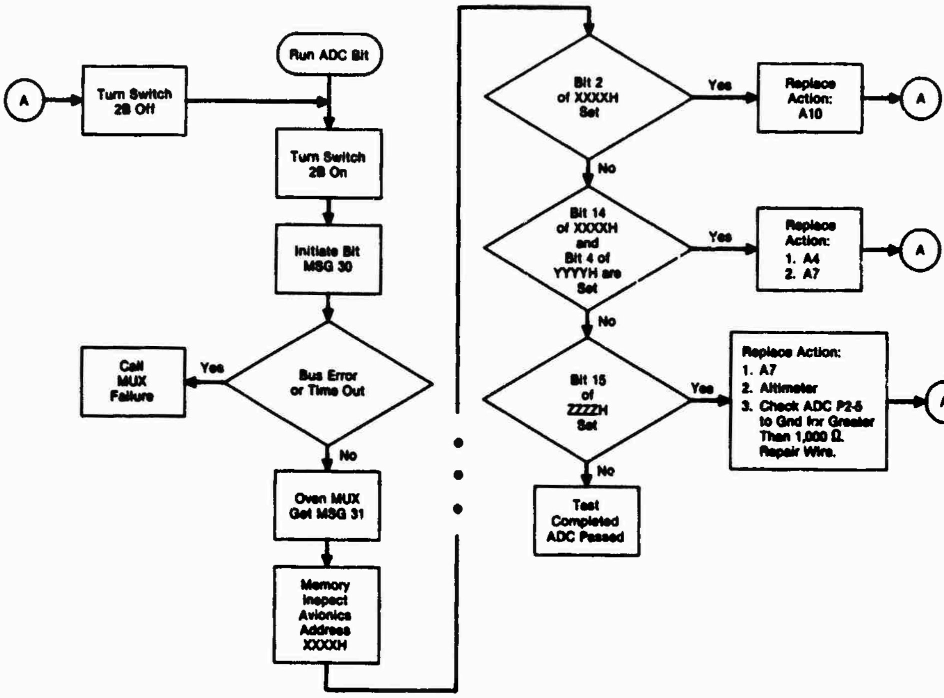

FIGURE 14
FAULT TREE EXAMPLE

The fault tree designers' ground rules were simple and limited in an effort to increase fault detection and decrease ambiguity sometimes at the expense of uniformity. The objective of the AFTA and therefore the fault tree designers was to repair the aircraft avionics. Secondary but important desirables included minimizing ambiguity groups and reducing dependencies on other WRA's.

The avionic subsystems possess varying architectures, consequantly a "standard" fault tree format is impossible. Although the fault trees, in flow diagram format, appear to be of the same form, they are highly dependent on the individual nature of equipment under test and therefore totally unique in approach. The flight control system fault tree greatly depends on the exceptional flight control system self test and aircraft memory inspection. With these two tools, the fault tree's expected ambituity averages less than two SRA's. In this example, some of the conventional assumptions in testing are unnecessary. For example, the flight control system fault tree calls out defective aircraft wires and even isolates multiple faulures. The AFTA fault trees will inform the operator of all SRA's that could cause the fault listed in descending probability of occurrence. In this way, repair of the aircraft is inevitable.

The use of peripheral WRA's was discouraged while testing a WRA. Where peripheral WRA's are required to perform a comprehensive examination of the unit under test (UUT), two stages of diagnostics were employed. The first phase allowed the use of the peripheral WRA and the second phase did not make this allowance. As a result, a limited test could still be performed regardless of the existance or condition of a dependent WRA. An example of such an arrangement can be seen on the simplified aircraft avionics block diagram of Figure 2. The Multipurpose Display Group (MDG) is a subsystem interfacing directly with the Avionics Multiplex Bus, and therefore the AFTA. However, the MDG possesses output circuitry that controls the Head-Up-Display (HUD). The MDG fault tree will use the HUD interface if the HUD is available; however, a test of the MDG avionics is performed regardless of the condition or even the existance of the HUD.

Because the AFTA is used at the aircraft (O-Level Maintenance), aircraft use must be minimized to maintain high operational readiness. Few of the fault trees require more than five minutes for execution. When a more comprehensive functional test becomes too long, that test is performed at the operator's discretion. An example is the Inertial Navigation Set (INS). Fault isolation takes a few seconds; however, it may be desirable to perform a drift check consuming 48 minutes. The operator is given the option of performing any test over and above the fault isolation requirements. Table I lists approximate fault tree execution times.

The fault tree originator was not allowed access points into the WRA such as test connectors or external stimuli. No aircraft doors are opened as a result of using the AFTA except to repair the faulty WRA. As mentioned earlier, the AFTA connects to existing nose wheel well connectors on the aircraft for both power and avionic multiplex bus access. The fault tree designer did have the controls in the cockpit at his disposal. Many of the WRA's under test receive stimuli from the aircraft as a result of operator activities within the cockpit.

AFTA'S EFFECTIVENESS

How effective is the AFTA? Significant effort has been expended to develop a theoretical prediction on AFTA's effectiveness. The parameters available for this study included the WRA fault tree, the BIT philosophy, and the expected failure rates of the WRA's and the SRA's. At this writing, a satisfactory algorithm tracking the empirical data has not been discovered. However, the empirical data gathered is very encouraging.

TABLE I

APPROXIMATE AFTA EXECUTION TIMES INCLUDING APPROPRIATE OPERATOR ACTION FOR SELECTED WRA's

WEAPON REPLACEABLE ASSEMBLY (WRA)	TEST TIME
Air Data Computer (ADC)	Milliseconds
Armament Computer (AC)	2 minutes
Wing Tip Decoders (WD)	2 minutes
Pylon Decoder (PD)	2 minutes
Fuselage Decoder (FD)	2 minutes
Gun Decoder (GD)	2 minutes
Head Up Display (HUD)	1 minute
Multiple Display Indicator (MDI)	2 minutes
MDI Repeater (MDRI)	2 minutes
Maintenance Signal Data Recorder (MSDE)	3 minutes
Maintenance Signal Data Converter (MSDC)	3 minutes
Control Converter (CSC)	2 seconds
Horizontal Situation Indicator (HSI)	2 minutes
Engine Performance Panel (EPP)	2 seconds
Up-Front-Control (UFC)	2 seconds
Flight Control Computer System (FCS)	3 minutes
Rate Gyro Assembly	3 minutes
Linear Accelerometer Assembly	3 minutes

There are two AFTA's at Cold Lake, Canada supporting seven of the avionic subsystems for seven aircraft. The same two AFTA's will be supporting 45 aircraft in Canada by October 1984. Eight preproduction AFTA's containing fault tree programs for 16 avionic subsystems will be delivered this year to three U.S. Navy bases in support of the F/A-18. To evaluate the effectiveness of the AFTA, an engineering data base has been designed and implemented. It is through this data base that AFTA's effectiveness will be determined. The data base will be updated by field personnel through a central management system. The data and any related reports will be accessible in real time to all AFTA users. This relational data base facilitates a variety of reports that may be sorted and grouped by any field and to any level. The record definition follows:

WRA NAME (5 bytes) - Character designator for the WRA being tested. The currently allowed names are INS, HSD, MDI, ADC, FCS, HUD, CSC.
WRA SERIAL NUMBER (14 bytes) - Vendor serial number for the unit under test.
DATE (11 bytes) - Initial date which testing began on the unit under test.
USER (22 bytes) - Name of person running test.
TEST SCHEME (3 bytes) - Method by which test was run.

ITB	Integrated Test Benches
A/C	Aircraft Testing
ATS	Automatic Test Equipment
SIM	Aircraft Simulator

TAIL NUMBER (7 bytes) - Tail number for aircraft on which test was run. Valid only if TEST SCHEME is A/C.
LOCATION (3 bytes) - Site at which test was run.

LMR	Lemoore
ETR	El Toro
CFD	Cecil Field
CLC	Cold Lake Canada

WRA TIME TO REPAIR (3 bytes) - Time to repair a WRA including time waiting for parts, time on aircraft, and time replacing SRA's. This entry is only valid if this data base entry has a classification of HIT (the WRA was repaired by the replace action below). Otherwise, this entry should have a value of zero.
TIME ON AIRCRAFT (3 bytes) - Time spent on aircraft in order to obtain the replace action found below. This record is a measure of aircraft usage.
SRA COUNT (2 bytes) - Number of SRA's called out by replace action.
PRIORITY (2 bytes) - Priority of SRA which failed. For example, if A1, A3, and A4 are called out in that order and A3 failed, then the priority is 2. If the failed SRA is not in the replace action, then the priority is 0.
CLASSIFICATION (3 bytes) - The classification of the diagnosis.

CND	Could Not Duplicate the failure squawked
HIT	AFTA correctly diagnosed the failure
MIS	AFTA incorrectly diagnosed the failure

FAILED SRA (3 bytes) - Up to three letter designator of failed SRA. For example, A13.
SRA LIST (30 bytes) - The list of SRA's AFTA called out in this replace action. Unused entries are set at 0.
COMMENTS (20 bytes) - User option.

Improving aircraft operational readiness, reducing spares density in the pipeline, and reducing maintenance costs have augmented the AFTA's popularity. The AFTA concept will be integrated into the avionics in future aircraft. Fault isolation to the SRA level should and will be accomplished on board and in real time. As VLSI devices become more versatile, fault isolating a large percentage of faults to a single SRA within the aircraft is a certainty. This fault detection and isolation capability will drastically reduce the need for second level maintenance, thereby allowing significant support savings.

As part of the preplanned product improvement program plan for the F/A-18 weapon system, a Flight Incident Recording/Aircraft Monitoring System (FIRAMS) was proposed. Although the FIRAMS primary purpose is flight incident and maintenance data recording, it has all of the components of an on-board AFTA. The FIRAMS provides communication through the AVMUX and it contains sufficient memory for the fault tree programs. The next quantum improvement in avionics support must be in the avionics systems themselves. Incorporation of the AFTA concept in the proposed FIRAMS need not and should not be limited in application to the avionics subsystem on the F/A-18. Significant improvements are foreseen in the area of engine in-flight fault detection and isolation extending even to incipient fault detection. Similar built-in-test improvements are envisioned for other "non-avionic" systems such as environmental control system, electrical generating system, aircraft hydraulic systems, etc.

The avionics of the near future must not be of the Von Neumann school of thought if the weapon capability to life cycle cost ratio is to be maximized. The electronics of the next generation weapon system should stress dedicated micro code as opposed to general purpose microprocessors. Each function will be modularized to the electronic card level and self tested to the component level. When dedicated processors are utilized, high level software and its related maintenance is reduced. These application directed architectures are gaining popularity in the commercial world as hardware costs decrease and software design and maintenance costs increase.

Because the currently designed AFTA takes the place of the Mission Computers aboard the aircraft, it can perform other non-maintenance related tasks. One such area is pilot training. Presently, an F/A-18 prospective pilot spends significant training time in an aircraft simulator. After basic familiarization, the pilot will log flight hours in a two seat T/F-18. The AFTA has the capability to generate various combat scenarios for on-the-ground training in the F/A-18 cockpit. The AFTA can simulate various air-to-air or air-to-ground missions by generating the appropriate weapons and radar displays and responding to pilot actions. In this approach, the aircraft can be used as a simulator when not required for operations resulting in a reduction in total training cost and an increase in pilot competence. This type of training need not be limited to pilot operations. The maintenance crew could be trained using such a device by programming aircraft fault indications and tutoring personnel on F/A-18 maintenance procedures.

The AFTA was originally conceived as a suitcase-sized flight line tester. However, the WRA's could be supported by the AFTA at the intermediate maintenance level if the aircraft environment is simulated. Such a simulator has been conceptually designed and is anticipated to be comprised of a single rack of equipment called the Aircraft Simulator (AIRSIM). The AIRSIM and an AFTA are depicted in Figure 15 as a WRA prescreener. Due to AFTA's short test time, most WRA's can be fault isolated and repaired without using the Avionics Test Set. Total I-Level throughput may be increased by an order of magnitude. The AIRSIM will be developed early in 1984.

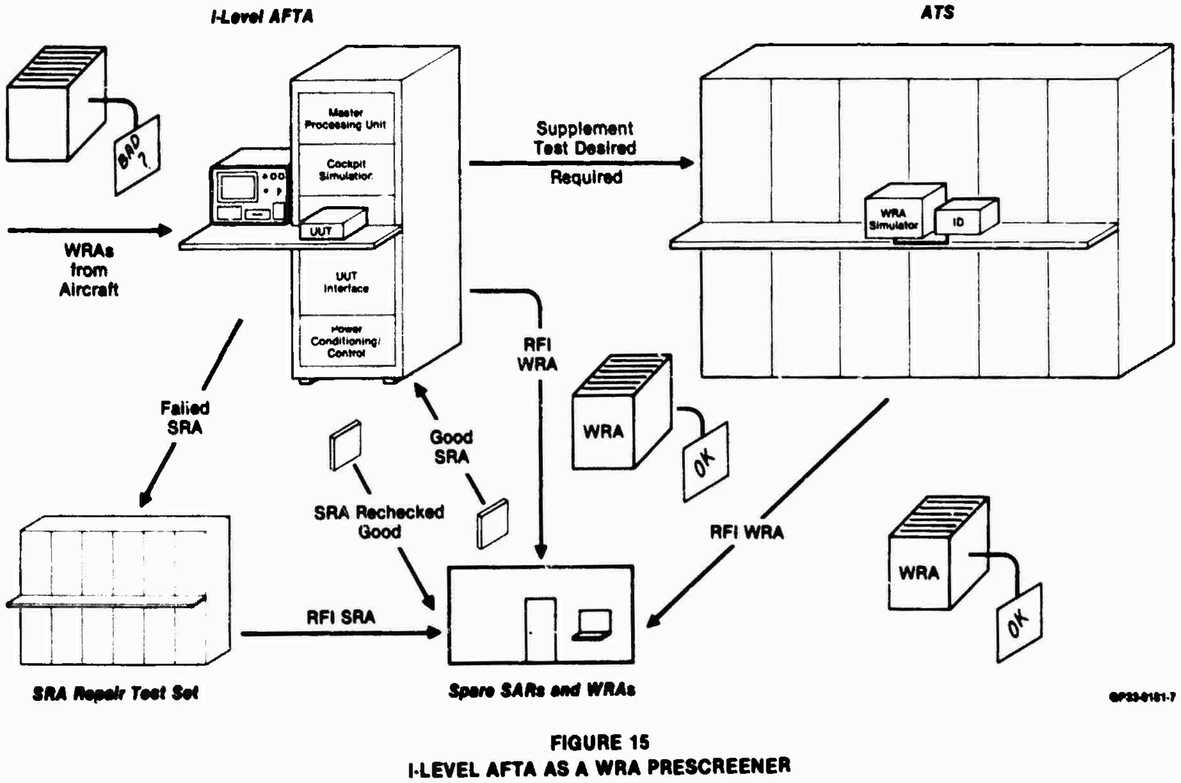

FIGURE 15
I-LEVEL AFTA AS A WRA PRESCREENER

REFERENCES:

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2. Comptroller General of the United States, "Operational and Support Costs of the Navy's F/A-18 Can Be Substantially Reduced," June 1980, LCD-80-65.

3. Kiesel, Harvey K., Support Equipment System Program Office Aeronautical Systems Division - AFSC, "BIT/SIT Improvement Project Evaluation of Selected USAF Aircraft BIT/SIT System/Subsystem," April 1979, ASD-TR-79-5013.

4. Yoder, Cornelia M. and Schrag, Merilyn L., IBM Corporation, "Nassi-Shneiderman Charts, An Alternative to Flowcharts for Design" - November 1978

DISCUSSION

W.H.Miller,

(1) Is the AFTA capable of off-loading the ATS and if so, by how much?

(2) Will MCAIR be marketing the AFTA or have marketing rights been sold to Australia?

(3) What is the ROM cost of AFTA, particularly its software?

Author's Reply

(1) Depending on the assumed AFTA effectiveness at I-level, very preliminary studies indicate the ATS workload can be decreased significantly (as much as 30%).

(2) AFTA's sold will be through MCAIR, but will be manufactured in Australia.

(3) The answer might be had through formal means via MCAIR.

R.Davies, Ca

With respect to the Avionic Fault Tree Analyser (AFTA) equipment – a 3-part organizational question prompted by the thought that organizational considerations sometimes impede technological progress:–

(1) Does the AFTA replace a T.O. (Tech. Order)?

(2) How does the maintenance man's supervisor fulfil his responsibilities?

(3) For the Canadian Forces, how does an unilingual French speaking technician get a simultaneous translation of an English language AFTA?

Author's Reply

(1) No. The AFTA refers to the T.O.'s in its instructions to the maintainer.

(2) The maintenance supervisor will make the same decision with or without an AFTA.

(3) The plasma display doesn't care what language is appearing on it. It can easily be translated.

J.F.Irwin, US

(1) Has the avionic BIT been adequate to allow for minimum ambiguity and how was it verified?

(2) How much additional diagnostic software had to be added to the AFTA to account for poor system/subsystem diagnostics?

(3) How are problems associated with interface problems resolved if at all with the AFTA?

Author's Reply

(1) The current avionics BIT is not adequate to eliminate ambiguity groups; however, they can be minimized. The fault tree diagnostics were verified by inserting faults into the avionics in the lab.

(2) As I indicated, the system/subsystem avionics diagnostics were designed for WRA fault isolation. The amount of software added to the AFTA was to extend the aircraft BIT to the SRA level. The fault tree program sizes range from 9 kbytes to 100 kbytes.

(3) Interfaces between WRA's other than the avionics MUX bus have been minimized in the F/A-18A aircraft; however, when they do exist leg discrete inputs (i.e. switches) of the fault tree will require the maintainer to toggle or exercise the appropriate interface. If the interface is between SRA's within a WRA the fault tree will go beyond WRA bit and perform memory inspections and functional testing of the interface. The AFTA cannot in all cases eliminate the ambiguity between the two or more SRA's and the interface media.

N.J.B.Young, UK

I was particularly interested in the use of your method to record intermittent faults as they occur in flight. We had a similar requirement and were obliged to use EEPROM technology for non-volatile storage. We had problems with this technology since it is low volume, very slow and of limited life, and so we had to perform data reduction only storing the first occurrence of each type of fault. Did you encounter the same problems and if so how did you overcome them?

Author's Reply

At this time the AFTA function is not in the aircraft. However, the feasibility mode/AFTA uses BUBBLE memory for off line storage. All message capture is stored in RAM; however, until the BUBBLE memory can be updated the BUBBLE memory is not cache memory, access time is in the order of milliseconds. BUBBLE memory has an impressive MTBF and does not wear out as rapidly as EEPROM or Floppy Disks.

W.G.Mulley, US

(1) Other than a printer, would an ECP for the F-18 require any other hardware changes or would all changes be in software?

(2) In second level testing, is a different UUT interface necessary for each unit as it was on VAST?

Author's Reply

There will be only one interface drawer for the 15 priority WRA's to be tested by the I-level AFTA.

(1) The extent of the ECP would depend on the method used to implement the AFTA function. A separate AFTA box would require wires added (i.e. power, MUX, printer, interface). If the implementation is with the mission computer, maintenance signal data recording system, and the cockpit displays, I would not anticipate hardware modifications.

MAINTENANCE PREMIER ECHELON INTEGREE DANS LES SYSTEMES D'ARMES

M.E.L. COURTOIS

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FRANCE

1. INTRODUCTION

La maintenance premier échelon a deux objectifs :

- la localisation des URP (Unités Remplaçables en Piste) en panne
- la validation des chaines fonctionnelles

qui doivent être atteints, dans les avions de combat modernes, en n'utilisant que des dispositifs embarqués. La maintenance intégrée dans les systèmes d'armes permet de répondre à ces impératifs en mettant à profit l'évolution technologique des équipements, l'architecture du Système d'Armes et le bus d'échange d'informations multiplexé "Digibus" à gestion centralisée, utilisé en particulier sur le MIRAGE 2000.

La maintenance intégrée présentée ici repose sur les principes de base suivants :

- Développement le plus complet possible des autotests dans les équipements quelle que soit leur technologie. Ces autotests peuvent être classés en deux catégories principales :

  . Autotests non perturbants, exécutés pendant le fonctionnement "opérationnel" de l'équipement. Les résultats de ces autotests peuvent être enregistrés dans le calculateur gérant du bus pendant le vol.
  . Autotests perturbants, déclenchés par le pilote ou le mécanicien, forçant l'équipement dans un mode de fonctionnement incompatible avec son utilisation "opérationnelle" dans le système d'armes.

- Mise à profit de l'architecture du Système d'Armes pour simplifier les opérations de maintenance par rapport aux méthodes classiques. En effet, les fonctions réalisées par le Système d'Armes résultent résultent de "chaines fonctionnelles" réalisant une ou plusieurs fonctions de transfert déterminées, obtenues par :

  . des éléments matériels qui sont principalement des circuits d'entrées-sorties, des liaisons filaires et dans certains cas des traitements analogiques sur les informations échangées
  . des éléments logiques et de calcul (constituant le logiciel), assurant à l'intérieur d'un équipement des liens privilégiés entre les entrées et les sorties et réalisant ainsi la fonction de transfert de l'équipement.

  Pour que le SNA remplisse correctement son rôle, il faut que les éléments matériels et les éléments logiciels soient tous deux intègres. Le principe de maintenance retenu consiste à effectuer des contrôles séparés :

  . d'une part des éléments matériels
  . d'autre part des éléments logiciels.

  Une vérification de l'intégrité de chacun de ces éléments conduit à valider l'ensemble du SNA. Par suite :

  . la vérification des éléments logiciels se fera en contrôlant par des tests appropriés leur intégrité, sans faire appel à un déroulement "opérationnel" des programmes.
  . la vérification des éléments matériels se fera en implantant dans les équipements (dotés en temps normal d'un logiciel opérationnel) des logiques particulières créant des liaisons aussi simples que possible (recopies) entre les entrées et les sorties de ces équipements, réduisant ainsi les contraintes liées à la mise en oeuvre des fonctions de transfert opérationnelles.

- Utilisation du digibus qui constitue, pour l'opérateur, une voie privilégiée de dialogue, permettant à partir d'une interface unique (le Poste de Commande de Navigation : PCN, par exemple) :

  . la lecture des informations de panne enregistrées au cours du vol
  . la lecture des informations reçues en analogique par les équipements qui, fonctionnant en "instruments de mesure" pendant les opérations de maintenance, retransmettent le résultat en numérique sur le Digibus
  . le positionnement des sorties analogiques des équipements qui, fonctionnant en "générateurs" pendant les opérations de maintenance, décodent les valeurs transmises par l'opérateur via le Digibus
  . la mise en oeuvre momentanée de programmes particuliers résidents ou chargés dans les équipements permettant d'accroitre la couverture des tests internes, et dont le déroulement serait incompatible avec le fonctionnement opérationnel.

- Utilisation des visualisations et signaliaations disponibles en cockpitt des tests déclenchés des équipements qui fournissent à l'opérateur dea moyens d'investigation complémentairea.

La séparation des contrôlea effectués sur lea élements matériela et lea éléments logiciela, liée à une utiliaation particulière des moyens disponibles dana l'avion permet, tout en conservant un contrôle de l'ensemble des fonctions du SNA, une réduction importante dea moyens à mettre en oeuvre.

La maintenance intégrée comprend deux parties :

- La maintenance a'exerçant pendant le fonctionnement opérationnel du SNA, basée sur l'exploitation des résultats :

  . ues autotests internes non perturbants des équipements
  . des surveillances du dialogue digibus dea équipements
  . des tests déclenchés pilote.

  L'ensemble de ces résultats est traité au niveau système par un logiciel exécuté par le gérant du digibus et dénommé "Comptes Rendus de Maintenance".

- La maintenance s'exerçant pendant un mode de fonctionnement particulier du SNA appelé "Fonctionnement Maintenance au Sol". Ce mode qui ne permet pas le fonctionnement opérationnel du système d'armes, et destiné à réaliser toutea les opérations de maintenance complémentaires aux autotests et tests déclenchés pilote. Il est mis en oeuvre à partir d'un logiciel résident dans le gérant du digibus constitué principalement d'une trame d'échange digibus particulière et de fonctions organisant le dialogue opérateur-système.

2 - MAINTENABILITE DES EQUIPEMENTS

Les systèmes d'armes intégrés au moyen du digibua posaèdent la particularité d'être géréa de façon centralisée au moyen d'un calculateur (dénommé "Calculateur Principal" ou "Tactique"). L'organisation des échangea eat donc le fait d'un équipement "maitre", gérant un flot d'informations circulant sur un support filaire unique (ligne de procédure et ligne de données). Afin de minimiser le nombre et l'ampleur dea équipementa de maintenance extérieurs à l'avion, il faut s'efforcer à ce que le moyen privilégié permettant les échanges d'informations opérationnelles soit ausai le moyen privilégié d'échange des informationa et dea procédures de maintenance.
La Société AMD-BA a édité un document de spécificationa générales de maintenabilité des équipements permettant d'homogénéiser les procédures de maintenance au niveau du systèmes d'armes et de définir l'aide que chaque équipement doit apporter à la maintenance globale de ce système.

2.1 - Matériels numériques

Lea matériela numériques échangent avec leurs équipementa périphériques par des circuits d'interface, des informations nombreuses, et variéea quant à leur forme (digibus, analogiquea, discrets ...) et aont dotés d'un logiciel complexe, comportant un nombre important de bouclea de programme dépendant dea modes de fonctionnement du Système d'Armes, des conditiona opérationnelles, de l'état des périphériques. Ila aont l'objet de contrôles ci-dessous :

- Contrôle par somme de contrôle (check-aum) du contenu mémoire programme :
  . en tâche principale à l'initialiaation
  . en tâche de fond pendant le fonctionnement.

- Contrôle de parité (lecture ou lecture-écriture) en permanence.

- Contrôle de la mémoire de travail (RAM ou RAX)
  . aoit à l'initialiaation seulement (en tâche principale)
  . soit à l'initialisation en tâche principale puia en tâche de fond
  . soit par test déclenché.

- Contrôle des unitéa de traitement
  . en tâche principale à l'initialisation
  . en tâche de fond pendant le fonctionnement.

- Contrôle du déroulement de programme par chien de garde (Watch-Dog) matériel en permanence.

- Contrôle des échanges : ils permettent de s'assurer du bon fonctionnement des circuita et dea lignes d'échanges d'informations. Les principea mia en oeuvre diffèrent suivant la nature dea échanges.

  . Echange digibus :
    - Test de connexion permanent permettant de a'assurer du bon fonctionnement du coupleur standard de digibus (COS).
    - Test conversationnel aur une poaition teat-mémoire, permanent, permettant de s'assurer du bon fonctionnement dea échangea d'information entre le processeur et et son interface digibus
    - Test converaationnel complet, exécuté pendant lea opérations de maintenance complémentaire au sol, et permettant la qualification exhaustive du couplage au digibus de l'équipement (décodage d'adreasea et contenu des informations).

. Echanges analogiques :
  - Entrées de paramètres : les équipements périphériques génèreot des excitstioos de valeurs connues, programmées par l'opérateur dans tout le domaine de variation et destinées aux circuits d'interface de l'équipement coosidéré. Ce dernier code ces paramètres et les transmet, par digibus, à des moyens de lecture à la disposition de l'opérateur (instruments de bord). L'opérateur compare les valeurs lues aux valeurs générées.
  - Sorties de paramètres : l'équipement reçoit par le digibus, une valeur de positionnement de la sortie considérée (valeur programmée par l'opérateur sur le PCN). Cette valeur est décodée et est exploitsble soit sur un instrument ou le PCN (via le digibus), soit rebouclée en interne sur les circuits d'entrée de l'équipement, codée, transmise par le digibus : elle est alors exploitée au PCN.

  Nota : les contrôles d'entrées ou de sorties vérifient aussi l'intégrité des câblages de liaison (tant numériques qu'analogiques).

- Logiciels d'aide à la maintenance
  Les contrôles de logiciel ou des échanges nécessitent un logiciel d'aide à la msintenance, capable d'sssurer les nouvelles fonctions de contrôle. Ce logiciel implique l'existence :

  - d'une trame d'échange correspondant aux besoins particuliers de gestion : c'est la trame maintenance qui vient compléter le trame opérationnelle ; elle réside en permanence dans l'orgsne de gestion.

  - de programmes spécifiques de dialogue opérateur-système par l'intermédiaire du PCN et de la visualisstion Tête Basse, qui résident en permanence dans l'organe de gestion. Ces programmes permettent en psrticulier d'accéder à des paramètres circulant sur le digibus (non exploités opérationnellement par le PCN ou la Visu Tête Basse) et d'élaborer des valeurs calibrées destinées aux équipements connectés au digibus.

  - de programmes d'side à la maintenance correspondant aux différents calculs et traitement de maintenance, tout particulièrement ceux de cootrôle des entrées et des sorties.

  Il y a lieu de remarquer que les paramètres opérationnels issus des calculs et circulsnt sur le digibus ne seront pas significatifs et par conséquent difficilement exploitables par l'opérateur. Mais leur validité dépendant de celle du logiciel et des échanges, ces psrsmètres "aveugles" sont indirectement controlés par les opérations de maintenance effectuées sur les logiciels et les interfaces.

2.2 - Matériels analogiques ou à logique câblée

De par leur nature, ces équipements ne peuvent être contrôlés que psr leurs sutotests et/ou par des excitations des entrées à des valeurs connues. Ces valeurs peuvent être fournies :

- soit à partir d'une information digibus décodée (si l'équipement est connecté au digibus ou par un équipement "source" qui, lui, est connecté au digibus).
- soit par la mise en configuration "test" de l'équipement
- soit par des moyens extérieurs à l'avion.

La lecture des informstions ainsi générées psr les équipements peut se faire :
- sur les visualisations disponibles en cockpit
- sur le PCN si l'équipement récepteur de l'information est connecté au digibus
- sur les prises de test de l'équipement ou de l'avion par un moyen spécialisé.

2.3 - Méthodes d'intervention

Les méthodes d'intervention diffèrent suivant qu'elles concerneot un problème de nature analogique ou de nature numérique :
- En analogique, ces méthodes demeurent "classiques"
- En numérique, il n'y a pas lieu de reproduire au sol l'anomalie détectée en vol mais :
  . d'une part, de vérifier l'intégrité du logiciel concerné (si besoin est)
  . d'autre part, de vérifier le fonctionnement des chaines matérielles (circuits analogiques, interfaces, voies d'échange numériquea et analogiques).

L'exécution de ces actions par les opérateurs est rendue possible psr la mise à disposition de moyens de dialogue internes à l'avion (en psrticulier l'adaptation du PCN et de la visualisation Tête Basse à la maintenance).

3 - COMPTES RENDUS DE MAINTENANCE

Les Comptes Rendus de Maintenance (CRM) permettent, en exploitant les résultats des autotests permanents non perturbants des équipements, de connaître l'état du système d'armes. L'intérêt de ce dispositif est d'autant plus grand que le taux de couverture des autotests des équipements est élevé. Le logiciel des Comptes Rendus de Maintenance a deux modes de fonctionnement :

- Les Comptes Rendus de Vol (CRV) : c'est la mémorisation et la datation de tnus les évènements de panne détectés par les autotests entre le moment du décollage et l'instant de l'atterrissage.

Ils permettent d'obtenir, au sol :

- la visualisation des équipements ou des URP qui sont tombés en panne pendant le vol, et qui ne sont pas revenus à l'état de Bon Fonctionnement au moment du toucher des roues (atterrissage).
- la visualisation de l'historique de vol, qui permet de connaître dans quel ordre et à quelles dates (en temps de vol) les équipements sont passés à l'état de panne.

- Les Comptes Rendus Sol (CRS) : c'est la possibilité de présenter au mécanicien ou au pilote l'état instantanné du système d'armes du point de vue des pannes, avion au sol. Il n'y a aucun enregistrement dans la mémoire du gérant et présentation :
  - soit des équipements ou des URP en panne
  - soit des mots d'information de panne de chacun des équipements suivant une sélection particulière

en temps réel.
L'exploitation des Comptes Rendus de Maintenance ne peut s'effectuer qu'au sol.

3.1 - Constitution des Comptes Rendus de Maintenance

Les Comptes Rendus de Maintenance comportent plusieurs informations :

- un Mot d'Etat et de Panne (MEP)
- un code Equipement
- un code de type de panne
- un mot de datation.

3.1.1 - Mot d'Etat et de Panne

Les mots d'Etat et de Panne (MEP) sont constitués à partir

- des Mots de Validité et d'Etat (MVE)
- des mots de mode
- des surveillances exercées par le gérant sur le dialogue digibus des équipements
- des surveillances particulières.

. Mot de Validité et d'Etat (MVE)
Un MVE est émis par chaque équipement connecté au digibus.
Ce mot comprend deux parties :

- Une partie "validité" qui indique aux équipements utilisateurs des informations générées sur le digibus que ces informations sont utilisables ou non.
  Cette partie du MVE n'est pas prise en compte pour l'élaboration d'un Mot d'Etat et de Panne (MEP).
- Une partie "état" (sous-entendu de pannes). Cette partie contient le compte rendu du résultat des autotests que l'équipement déroule en permanence et éventuellement un bit de synthèse de panne par URP pour les équipements multi-URP.

. Mot de Modes (MM)
Ce mot indique le mode dans lequel l'équipement fonctionne. C'est dans ce mot que l'on trouve l'information "Test en Cours". Le mot de mode, ou une partie de ce mot, est pris en compte pour l'élaboration d'un MEP.

. Surveillance Digibus
Le dialogue Digibus de tous les équipements qui y sont connectés est surveillé par le gérant du système qui détermine des pannes dialogue éventuelles.

. Surveillances Particulières
Ces surveillances sont de deux ordres :

- Les équipements non connectés au digibus ont un certain nombre d'autotests qui renseignent sur leur état. Ces autotests concourent à l'élaboration d'un ou de plusieurs discrets de bon fonctionnement qui sont transmis
  - soit vers le gérant du système
  - soit vers un équipement qui, relié au Digibus, le transmettra vers le gérant.

  Le gérant a donc la possibilité de confectionner un MEP pour l'équipement émetteur des discrets de bon fonctionnement en question.

- Les équipements envoient soit vers le gérant soit vers d'autres équipements un certain nombre d'informations analogiques ou Digibus. Les équipements récepteurs peuvent faire des tests de vraisemblance sur les informations qu'ils reçoivent, et peuvent donc déterminer des pannes sur les "émetteurs".
  Les résultats de ces surveillances sont :
  - soit directement élaborés par le gérant lorsqu'il effectue lui-même ces contrôles
  - soit disponibles dans un équipement relié au digibus qui les retransmettra vers le gérant

Le MEP est donc le rassemblement de toutes ces informations sur 2 mots de 16 bits dans lesquels on trouve :

- des bits qui donnent le résultat des autotests d'un équipement
- des bits qui donnent le résultat des surveillances effectuées sur un équipement par ses périphériques ou le gérant du système.

3.1.2 - Code Equipement

Chaque équipement faisant l'objet d'un CRV possède un code qui n'a de valeur que pour le gérant du système. Les équipements sont ainsi hiérarchisés implicitement dans la table des Comptes Rendus de Maintenance. Ce code équipement comprend 8 bits.

3.1.3 - Code de type de panne

4 types de panne peuvent être déterminés. Le code de type de panne comprend 2 bits.

Pannes de type 1 : Ce sont les pannes déterminées par les autotests des équipements, ou par le gérant sur leurs tests dialogue digibus. Ce type de panne permet de considérer que la maintenance est réalisée par l'échange de l'URP fautive sans qu'il soit nécessaire d'effectuer des recherches complémentaires.

Pannes de type 2 : Ce sont toutes les pannes autres que celles déclarées par les équipements eux-mêmes par l'intermédiaire de leurs autotests ou le gérant sur la qualité du dialogue digibus. Ce sont donc des pannes détectées par les "surveillances particulières". Dans ce cas, il y a peut-être lieu d'effectuer des recherches complémentaires avant de déposer l'URP.

Pannes de type 0 : Dans le cas où il y a panne puis retour à bon fonctionnement, il y a indication de type de panne 0 au moment du retour à l'état bon fonctionnement.

Pannes de type S : Dans le cas où une URP a fait l'objet de dix enregistrements de panne pendant le vol, elle est présentée avec indication de type de panne "S" pour "SATURANTE", quel que soit le type de panne du dernier enregistrement : "1", "2" ou "0".

3.1.4 - Mot de Datation

En vol, cheque compte rendu de maintenance est enregistré en même temps que l'heure à laquelle la panne correspondante a eu lieu. Cette heure est exprimée en nombre de cycles longs d'échange Digibus. Le LSB de ce mot a une valeur de 160ms dans le cas du MIRAGE 2000.

3.2 - Constitution des Comptes Rendus de Vol (CRV)

Les Comptes Rendus de Vol sont la mémorisation des Comptes Rendus de Maintenance entre le moment du décollage et le moment de l'atterrissage, dans la mémoire du calculateur gérant le Digibus. Cette table est mémorisée dans une zone RAM ou RAX protégée.

3.2.1 - Datation

Le compteur servant à dater les CRV est mis à zéro une première fois lors du passage sur la position "Nevigation" du Sélecteur de Mode de Navigation. Lors du décollage, matérialisé par l'information "Train détendu" le logiciel des CRV doit enregistrer la valeur de ce compteur. Ceci permet de connaître l'heure de décollage par rapport au passage en "Navigation". Dans le même temps, ce compteur sera remis à zéro afin de pouvoir dater les CRV par rapport au moment du décollage.

3.2.2 - Remise à zéro de la table des CRV

La table des CRV est remise à zéro lors de le première information "train détendu" consécutive à la mise sous tension du Système d'Armes.

3.2.3 - Enregistrement des CRV

Au moment du décollage, (train détendu) il y a :
- Remise à zéro de le teble des CRV (du vol précédent)
- Enregistrement de l'heure de décollage (par rapport au pessege en NAV)
- Remise à zéro du compteur horaire
- Compareison des MEP constitués dans le premier cycle long suivent le décollage et comparaison evec le profil "Bon Fonctionnement" de checun d'eux.

Ensuite, il y a constitution et mémorisetion d'un CRV :
- lors du passage d'un MEP de l'état Bon Fonctionnement à l'état panne
- lors du passage d'un MEP d'un état de panne à un autre état de penne
- lors du passege d'un MEP d'un état de penne à l'étet de bon fonctionnement.

Cheque MEP feit l'objet d'une compareison per cycle long d'échenge (160ms). La mémorisation des CRV s'errête lorsque le contact de trein indique "Sol" (Trein écresé).

3.2.4 - Limitetions

- Un MEP donné ne peut être enregistré que 10 fois au maximum eu cours d'un vol
- Le nombre totel de mémorisetions de CRV est limité à 128 pour un vol.

3.2.5 - Voyent magnétique

Tout enregistrement dens le table des CRV feit besculer un voyent magnétique sur le tebleeu mécanicien. L'enregistrement de l'heure de décollege ne feit pas basculer ce voyent qui est réarmable manuellement au sol.

3.3 - Constitution des Comptes Rendus Sol (CRS)

Les Comptes Rendus Sol sont constitués par une table non sauvegerdée dans le gérant du Digibus. Cette table est constituée par les comptes rendus de maintenance instantannés de tous les équipements du Système d'Armes.

Dans le CRS :
- La datation est forcée à zéro
- Il n'existe pas de panne de type "SATURANTE".

3.4 - Procédure de visualisation des Comptes Rendus de Vol

La visualisation des Comptes Rendus de Vol s'effectue sur la Tête Basse, au sol.

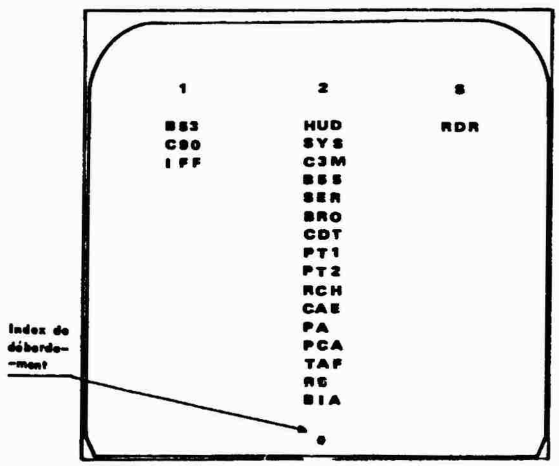
3.4.1 - Visualisation des pannes existant à la fin du vol

La liste des URP en panne au moment de l'atterrissage est présentée en tête basse.

Il apparait :

- Une 1ère colonne de mnémoniques de couleur verte, surmontée du chiffre 1 tracé en vert. Les mnémoniques de cette colonne correspondent aux URP en panne de type 1.
- Une 2ème colonne de mnémoniques de couleur ambre, surmontée d'un 2 ambre. Ces mnémoniques indiquent les URP en panne de type 2.
- Une 3ème colonne de mnémoniques de couleur rouge surmontée d'un S rouge. Ces mnémoniques indiquent les URP en panne saturante (type S).

Chaque colonne comporte au plus 16 mnémoniques. Lorsque le gérant demande la visualisation de plus de 16 mnémoniques dans une colonne, la tête basse ne visualise que les 16 premiers et présente un astérisque en bas de colonne. L'opérateur doit alors se reporter à l'historique de vol pour connaître la liste complète des URP ou équipements en panne.
Si aucune URP ou équipement n'est en panne, seuls apparaissent le 1 vert, le 2 ambre et le S rouge.



VISUALISATION DES PANNES EXISTANT EN FIN DE VOL

3.4.2 - Visualisation de l'historique de vol

L'historique de vol est constitué par l'ensemble des CRV qui ont été enregistrés pendant le vol, dans l'ordre chronologique de leur mémorisation. Il est présenté en tête basse.
Dans ce mode de visualisation le premier affichage est celui du nombre de mémorisations de CRV effectuées en vol, suivi de l'heure de décollage exprimée en heures, minutes, secondes, dixièmes de seconde.

Le second affichage est celui du 1er CRV enregistré, sous la forme de 4 lignes superposées :

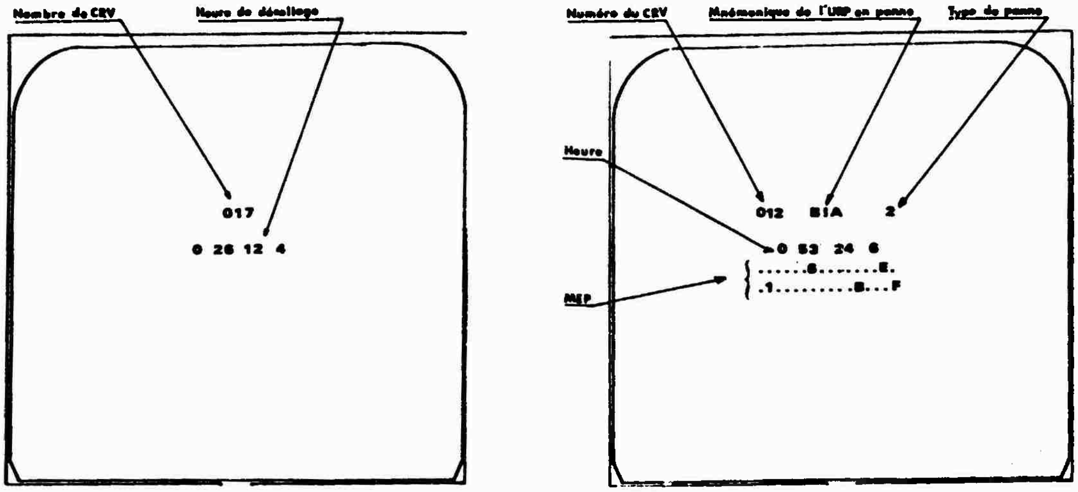
- La première ligne indique le numéro d'ordre du CRV, l'équipement concerné et le type de panne (0, 1, 2 ou S)

- La seconde ligne indique l'heure de mémorisation en heures, minutes, secondes, dixièmes de seconde.

- Les 3e et 4e lignes de 16 caractères chacune reproduisent le MEP correspondant. Pour tout bit à 1 dans le MEP on visualise un point et pour tout bit à 0 (c'est-à-dire significatif de panne), le rang du bit dans le mot du MEP.

On peut ensuite dérouler tous les CRV d'un vol dans le sens croissant ou décroissant.

L'heure de décollage est toujours présentée à l'appel de la procédure.
Si aucune mémorisation de CRV n'a eu lieu en cours de vol, il y aura au moins l'heure de décollage inscrite sur la tête basse.



1re AFFICHAGE

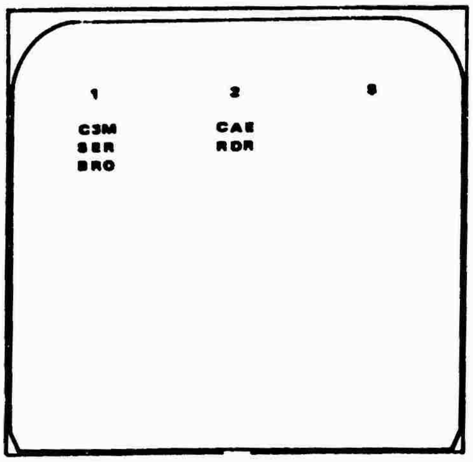
AFFICHAGE COURANT

VISUALISATION DE L'HISTORIQUE DE VOL

3.5 - Procédure de visualisation des Comptes Rendus Sol
Les Comptes Rendus Sol ont pour but de présenter l'état instantanné du système du point de vue des pannes. La visualisation s'effectue sur la Tête Basse, au sol.

3.5.1 - Visualisation des Equipements en panne actuelle
La liste des URP en panne actuelle est présentée sur la Tête Basse.

La visualisation présentée est semblable à la liste des URP en panne des Comptes Rendus de Vol. La colonne des pannes saturantes est vide car une panne actuelle ne peut pas être saturante.



VISUALISATION DES EQUIPEMENTS EN PANNE ACTUELLE

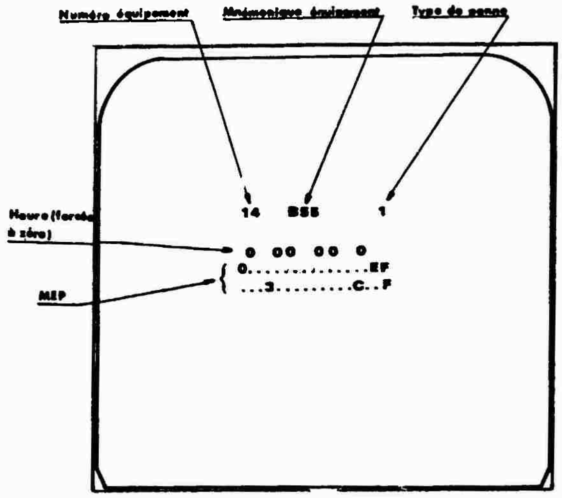
3.5.2 - Visualisation de l'état actuel d'un Equipement

L'état actuel d'une URP est présenté sur la Tête Basse.

Pour visualiser l'état actuel d'une URP, on frappe au PCN un nombre de 2 chiffres, qui est le numéro dictionnaire de l'équipement auquel l'URP est rattachée. Apparait alors en tête basse un Compte Rendu Sol sous forme d'un ensemble de 4 lignes.

- 1ère ligne : numéro de l'équipement, nom de l'équipement, type de panne (1, 2, 0)
- 2e ligne : date, forcée à 0
- 3e et 4e lignes : MEP de l'équipement, présenté comme en visualisation de l'historique de vol.

La frappe d'un autre numéro fait apparaitre le Compte Rendu Sol correspondant en lieu et place du précédent.



VISUALISATION DE L'ETAT ACTUEL D'UN EQUIPEMENT

3.6 - Panne d'un équipement utilisé pour les Comptes Rendus de Maintenance

En cas de panne du calculateur gérant, celle-ci est indiquée par les visualisations opérationnelles. Les mémorisations de CRV déjà effectuées sont perdues. Aucun nouveau traitement ne peut être effectué et il est donc impossible de présenter un compte rendu quelconque. En visualisation de Compte Rendu de Maintenance, le gérant secours provoquera la visualisation des réticules 1, 2 ou S avec le mnémonique CP en colonne 1.

En ce qui concerne les autres équipements nécessaires à la visualisation des comptes rendus de maintenance, les pannes éventuelles seront détectées par les autotests déclenchés, plus performants que les autotests permanents.

4 - MAINTENANCE COMPLEMENTAIRE AU SOL

Les autotests permanents des équipements et du système ont une certaine limite du fait qu'ils doivent se dérouler sans perturber le fonctionnement opérationnel. Il s'en suit que la profondeur des tests n'est pas toujours suffisante pour détecter et localiser les pannes avec la performance attendue d'un premier échelon.

La maintenance complémentaire au sol doit donc permettre de compléter les autotests permanents en rendant possible la vérification de tous les éléments qui ne peuvent l'être qu'en perturbant le fonctionnement opérationnel du système d'armes. Les principales fonctions à assurer sont les suivantes :

- Validation des transmissions d'informations analogiques entre les différents équipements et avec les armes.
- Permettre des tests plus profonds dans les équipements en utilisant des tests déclenchés spécifiques dont les algorithmes sont soit résidents dans les équipements, soit "chargeables" à partir d'une mémoire de masse.
- Qualification exhaustive du dialogue digibus des équipements.

L'exécution de ces différentes fonctions est rendue possible par les logiciels d'aide à la maintenance sol. Ces logiciels sont répartis en deux groupes :

- Les logiciels de base
- Les logiciels complémentaires.

4.1 - Logiciels de base

Ces logiciels permettent de donner au mécanicien tous les moyens de dialoguer avec le système afin qu'il puisse mener à bien toutes les opérations de vérification qui lui semblent nécessaires afin de localiser une panne ou de valider une chaine fonctionnelle.

4.1.1 - Logiciel Trame Sol

En configuration maintenance au sol, le système fonctionne suivant un mode particulier.
Il faut considérer deux types d'équipements :

- Les équipements analogiques pour lesquels les opérations de maintenance ne peuvent se faire qu'en utilisant le mode de fonctionnement opérationnel et en simulant à l'entrée un ensemble de paramètres cohérents.

- Les équipements programmés numériques pour lesquels le fonctionnement maintenance est particulier, le programme opérationnel est arrêté au profit d'un programme permettant :
  . de positionner directement à une valeur donnée par le Digibus les différents paramètres de sortie analogiques (hors Digibus).
  . de coder sur le Digibus la valeur de toutes les entrées analogiques
  . d'accueillir dans leur mémoire RAM et d'exécuter des logiciels chargés à partir du Digibus
  . de dérouler, à partir d'un ordre donné par le Digibus, des tests internes complémentaires.

Les valeurs de positionnement des paramètres de sortie analogiques sont délivrées à l'aide de Codes de Données Maintenance de Positionnement (CDMP).
Les valeurs des paramètres analogiques d'entrée sont données dans les Codes de Données Maintenance de Lecture (CDML).
Le déclenchement des logiciels de test chargés et des tests complémentaires s'effectue à l'aide des Codes de Données Maintenance de Déclenchement (CDMD).
La trame sol est donc le support de la transmission des informations nécessaires à la réalisation des fonctions décrites ci-dessus.

La trame sol comprend :

- Tous les messages émis sur Digibus en trame opérationnelle mais dont la cadence est réduite à une fois par cycle long et dont le contenu n'est pas significatif ; ceci d'une part pour ne pas avoir une trame d'échange trop complexe et trop chargée à gérer, et d'autre part, pour ne pas avoir une charge de calcul trop importante au niveau du gérant du digibus. Cependant, un certain nombre d'équipements demandent que quelques échanges s'effectuent au "rythme opérationnel" afin de pouvoir conserver un fonctionnement maintenance correct.
- Les messages permettant de valider les chaines analogiques, c'est-à-dire les CDMP et CDML
- Les messages permettant de charger dans les équipements des logiciels de test
- Les messages permettant de déclencher des tests complémentaires chargés ou résidents (CDMD)
- Les messages permettant de lire et/ou d'écrire dans la mémoire du gérant ou des équipements
- Les messages de visualisation maintenance sur le PCN et la Tête Basse.

4.1.2 - Logiciel de Dialogue Système

La gestion des CDMP, CDML, CDMD est faite par le mécanicien. Lors du passage de la trame opérationnelle à la trame maintenance sol, les valeurs des CDMP sont telles qu'elles définissent un état initial maintenance pour le système ; a priori, toutes les valeurs sont positionnées à zéro. Les CDMD sont toutes positionnées à zéro. Le logiciel de dialogue permet au mécanicien :

- de positionner les paramètres analogiques à une valeur choisie par lui,
- de lire les valeurs des paramètres analogiques choisis par lui
- de déclencher les tests complémentaires à son initiative.

L'organe de dialogue utilisé est le Poste de Commande de Navigation (PCN) qui possède toutes les commandes nécessaires, ainsi que les éléments de visualisation indispensables. La tête basse est utilisée comme bloc-notes, c'est-à-dire qu'elle permet de conserver l'affichage des huit dernières opérations effectuées au PCN.
De plus, ce logiciel permet de donner au mécanicien toutes les informations nécessaires pour surveiller le fonctionnement maintenance du système d'armes.

4.1.3 - Gestion des logiciels complémentaires

Les logiciels complémentaires sont chargés soit dans le gérant soit dans les équipements à partir d'une procédure définie par ce logiciel de gestion. Les logiciels à exécuter sont contenus dans un support informatique interne ou externe à l'avion et connecté au digibus. Ce logiciel de gestion ne concerne que le chargement des logiciels à exécuter. L'exploitation des résultats des traitements effectués par les logiciels chargés est assurée par le logiciel de dialogue système.

4.1.4 - Gestion de l'outillage sol

Ce programme de gestion permet le dialogue avec un équipement au sol connecté au digibus.
Il rend possible :

- La lecture de tout ou partie de la mémoire d'un équipement par un outillage sol
- L'écriture en mémoire dans les équipements.

4.2 - Logiciels Complémentaires

Les logiciels complémentaires sont contenus dans un équipement interne ou externe au système et chargés dans les équipements à l'aide du programme de gestion des logiciels complémentaires.
Ils se divisent en deux groupes :

4.2.1 - Logiciels complémentaires de test système

Ces logiciels sont chargés et exécutés dans le CP et ont pour but d'exécuter un test particulier s'adressant à tout ou partie des équipements du Système d'Armes. Ainsi, le logiciel de Test Conversationnel Complet (TCC) permet de qualifier à cent pour cent la qualité du dialogue digibus de tous les équipements du système d'armes.

4.2.2 - Logiciels complémentaires de test équipement

Ces logiciels sont chargés et exécutés dans les équipements y compris le gérant. Ils sont exécutés en interne dans les équipements concernés et ne s'adressent en aucune façon à un de leurs périphériques.
Ils peuvent être considérés comme des autotests internes complémentaires.

Nota : Il faut bien remarquer que la maintenance intégrée ne consiste pas à rechercher une panne par un processus automatique mais à donner au mécanicien tous les outils nécessaires à la conduite d'un dépannage ou à la validation d'une chaine fonctionnelle.

4.3 - Mise en oeuvre des Logiciels de base d'Aide à la Maintenance Sol

Le système d'armes ne peut passer en configuration maintenance qu'à partir du fonctionnement opérationnel.
L'avion étant sous tension, le passage de la configuration opérationnelle à la configuration maintenance ne peut s'effectuer que si :

- Les conditions de sécurité armement sont réunies
- Le train est vérouillé bas
- Le commutateur secondaire du PSM est sur la position "MAINT"
- Le mécanicien a frappé au clavier du PCN le code de demande "Trame Sol".

A la réception de ce code par le gérant, celui-ci émet, en trame opérationnelle et une seule fois, un code d'ordre de commutation en fonctionnement maintenance des équipements. Ensuite, il y a un silence Digibus de 2 cycles longs pour permettre l'initialisation des équipements en fonctionnement maintenance puis émission de la trame maintenance proprement dite.
Le passage de la configuration maintenance à la configuration opérationnelle du système d'armes s'effectue par :

- la mise sur une autre position que "MAINT" du rotacteur secondaire du "PSM"
- la mise hors tension puis sous tension du système d'armes.

5 - CONCLUSION

Le principe de maintenance intégrée décrit ici, a été étudié de telle sorte que les dispositifs de maintenabilité représentent un pourcentage faible des matériel et logiciel des équipements.
Au niveau système, le logiciel représente environ 25kmots de programmes résidents pour un avion comme le MIRAGE 2000.

Les avantages de cette maintenance intégrée sont multiples :

- Grande indépendance par rapport aux évolutions des logiciels équipements
- Recherche de panne sans simulation des conditions de vol
- Mise en oeuvre sans utilisation de moyens de test extérieurs à l'avion sauf en ce qui concerne les capteurs et certains circuits d'armement
- Exploitation sur avion des résultats avec possibilité d'avoir une bonne connaissance de la nature et de la durée des pannes qui se sont produites en vol et qui ne sont pas toujours décelables au sol.
- Mise en oeuvre quasiment instantannée des logiciels permettant les recherches de pannes, ou les validations de chaines fonctionnelles du Système d'Armes.
- Grande souplesse dans les procédures à utiliser pour effectuer un dépannage, le mécanicien utilisant au mieux et à sa seule initiative, les dispositifs développés dans le Système.

COMPUTER GRAPHICS TECHNIQUES FOR AIRCRAFT EMC ANALYSIS AND DESIGN

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SUMMARY

This paper describes a comprehensive computer-aided system for the prediction of the potential interaction between avionics systems, with special emphasis on antenna-to-antenna coupling. The methodology is applicable throughout the life cycle of an avionic/weapon system, including system upgrades and retrofits. As soon as aircraft geometry and preliminary systems information becomes available, the computer codes can be used to selectively display proposed antenna locations, emittor/receptor response characteristics, electromagnetic interference (EMI) margins and the actual ray-optical paths of maximum antenna-antenna coupling for each potential interacting antenna set. The visibility of the entire interaction matrix produces an appreciation and awareness that had heretofore been unavailable. Antennas can be interactively relocated by track-ball (or joystick) and the analysis repeated at will for optimization or installation design study purposes. The codes can significantly simplify the task of the designer/analyst in effectively identifying critical interactions among an overwhelming large set of potential ones. In addition, it is an excellent design, development and analysis tool which simultaneously identifies both numerically and pictorially the EMI interdependencies among subsystems.

1. EMC IN AVIONIC/WEAPON SYSTEM INTEGRATION

Electromagnetic Compatibility continues to be a vital but elusive component of Avionic/Weapon System Integration. Many modern examples illustrate the need to identify and solve potential problems of electromagnetic interference as early as possible in the development cycle of an avionic system so that expensive modifications on production configurations can be avoided or at least minimized. In effect, compatibility should be designed into the system. Such a philosophy is inherent in the requirements of the specification for avionic system compatibility (MIL-E-6051) and that for weapon system integration (MIL-HDBK-335). However, the implementation of this goal remains a formidable task in spite of recent computer-aided analysis techniques (Spina), primarily because of the large number of the likely interactions that must be analyzed and the mass of data that must be evaluated.

Undesired interactions can be categorized as intersystem, i.e. self-compatibility problems, or intrasystem, i.e. problems between the different avionics subsystems of a major weapon system. Perhaps the most cohesive development of the methodology of intrasystem analysis is fostered by the U.S. Airforce at the Rome Air Development Center under its Intrasystem Analysis Program (IAP)(Spina). Undesired intrasystem coupling mechanisms arise from antenna-to-antenna, wire-to-wire, case-to-case, electromagnetic field to wire or case and common mode coupling. The IAP effort has resulted in three major computer codes for EMC analysis (Spina):

IEMCAP - Intrasystem Electromagnetic Compatibility Analysis Program

GEMACS - General Electromagnetic Model for the Analysis of Complex Systems

and NCAP - Nonlinear Circuit Analysis Program

IEMCAP has been intended to include most of the coupling modes in a comprehensive intrasystem EMC analysis; GEMACS is intended for EM radiation analysis and NCAP can be used to determine the nonlinear transfer functions of electronic circuits. Other EMC analysis tools (Hodes and Widmer) have been developed for the computer-aided analysis of antenna/antenna coupling. However, all of these "batch" executed programs suffer from the inherent problems of this computer aided process and the inherent problems of input and output data quality and size that are associated with the computer programs themselves.

2. DATA MANAGEMENT AND INSIGHT

Experienced users of large computer programs have come to identify input data validation as an important and non-trivial first step in the process of producing credible results (Miller). Associated with this is the need to appreciate the degree to which the input data models the desired features of the physical system that is being analyzed. Continuity of analytical thought is difficult to maintain in depth while waiting to analyze the output data of a "batch" process.

The batch programs mentioned above often require a complex input data set and do not have a simple procedure to verify its correctness. The tabulated output data, even though comprehensive, forms a massive amount of information that must be methodically analyzed to identify critical EMC areas. A total overview and an insightful appreciation of detail do not come easily to this process. By its nature, it requires considerable time, skill and training of the EMC engineer.

The AAPG computer program was created with the purpose of reducing these major problems of EMC analysis. It is a menu-driven interactive graphics system that responds to the user's need for data validation, by producing organized displays of input data and at the same time produces comprehensive displays of the results of the EMC analysis in a fashion that deepens the user's insight into the modelling process. AAPG was developed at Concordia University, Montreal, Canada under the sponsorship of the Defence Research Establishment Ottawa (DREO). In 1980, IITRI engineers at the U.S. Department of Defense Electromagnetic Compatibility Analysis Center (ECAC) undertook intensive operational use of AAPG under the sponsorship of the USAF Rome Air Development Center (RADC) Compatibility Measurements Section and since that time DREO, Concordia, ECAC, and RADC have carried out joint development of AAPG. It is designed to analyze antenna-to-antenna coupled electromagnetic interference (EMI). Details of such an analysis have been described by Weinstock(5). The quantity that is computed is called the narrow-band EMI Margin. It is the undesired signal level at the receiver in dB above its threshold level. This is computed from the spectral characteristics of each interacting transmitter and receiver, the gain patterns, and cabling losses of the two antennas involved and the coupling loss in the path between the transmitting and receiving antennas. For modern aircraft with many avionic systems with multiple antennas this value must be computed for each likely interacting antenna pair.

A useful representation of the ensemble of interactions is that described by Spina (3) where the total set of interactions is visualized as consisting of an Interference Interaction Sample Space matrix with interaction elements T_{ij} between i^{th} transmitter and the j^{th} receiver. Each of these elements must be examined and evaluated in order to reduce the sample space to those elements that are critical, i.e., where the EMI Margin exceeds preset values. It should be useful for the reader to visualize such a sample space and from the illustrations note how the AAPG analysis and displays help to quantify the T_{ij} elements, at the same time producing an appreciation of the validity of the modelling process.

3. STRUCTURE OF AAPG

Two major software modules form the heart of the AAPG system. These are shown in Figure 1. The Electromagnetic Compatibility Computation System acts on the input data file and accurately computes the antenna-to-antenna coupled interference and stores all relevant data in a mass storage file that is accessed by the Graphics Data Management System. This latter system is composed of four distinct sub-modules for displaying frequency coincidence data, antenna position, the EMI margin data, and a template to assist in the re-positioning of antennas. The GDMS identifies itself with a menu that lists these modules as well as a "HELP" module which provides execution information for the user, should he forget the simple mnemonic commands or available options. Each of the four modules has its own menu of simple commands including a "HELP" command that produces specific instructions for each module. Each of these modules will be described. The reader should note how in addition to output data display the input data can be easily verified by visual examination. Hard copies of each illustration can be accumulated to form a comprehensive analysis report.

4. IDENTIFYING AND BOUNDING THE T_{ij} ELEMENTS

An entry T_{ij} in the Interference Interaction Sample Space will occur whenever there is frequency coincidence between a transmitter spectral emission, be it fundamental or harmonic, and the receiver spectral response. The EMCCS identifies these combinations and the frequency ranges over which they occur. This data is available first in tabular form that consists of a listing of each receiver and the corresponding transmitters that can produce frequency coincidence. A typical entry is shown in Table 1.

Table 1 - Frequency Coincidence Tabulation

```
----------------------
RCVR           XMTR

       ARA25

1DFRX              5---------
     1.01 HFSST     ---------
     1.02 HFAMT     ---------
     1.03 UHFTX
     1.04 UHFAMT
     1.05 VHFFMT

2---------
 ---------
```

Table 1 shows that five transmitters can be expected to interact with the first receiver. Each combination is numbered, i.e. 1.03, etc. This numbering is used to command displays of these combinations for more detailed examination. Hence the user will obtain a hard-copy of this entire listing and use it as a working reference during an analysis session.

Where no frequency coincidence occurs, the listing so indicates. Thus the emittor/receptor interactions are identified. A listing of the associated frequency ranges can be obtained if it is of interest. No explicit appreciation of power level differences is available at this point. To begin this power level quantization, plots of emittor/receptor frequency coincidences can be obtained. These are superpositions of emittor and receptor spectral responses as shown in Figure 2. The simple command that produces them is shown in the lower right hand corner. Note these displays are self-contained and complete. They represent plots of the actual input data used to characterize the systems and as such provide ready verification of their characteristics. Hard copies of the complete set can provide a complete graphic record that can be annotated as say measurement data becomes available. The region of frequency coincidence is now clearly visible as are the associated power level differences. A cursor mode is available to provide more precise readout of frequencies and power levels. It can be seen that a set of these plots alone can be a useful tool for the planning of frequency combinations for ground and flight test purposes.

At this stage then, T_{ij} has been bounded in frequency and power level for narrowband interaction between individual systems. To determine whether the power level difference can be expended by propagation path coupling loss between associated antenna pairs, the geodesic path between the antennas on the aircraft model must be computed. Although the actual aircraft model and antenna locations are shown in later EMI margin displays, a separate graphics module has been provided in order to validate and document the aircraft model, the antenna locations and the antenna radiation pattern characteristics.

5. ANTENNA POSITION DISPLAY

The aircraft model and the location of each of the subsystem antennas can be verified in the Antenna Position module. Figure 3 illustrates a typical subsystem display. The lower right-hand corner lists the command that produces it. The viewing angle can be selected at will to coincide say with that used for aircraft installation drawings. The locations of the antennas for the subsystem are shown as coded symbols and tabulations of coordinates of location allow easy verification with aircraft drawing data. The approximate radiation pattern model that is specified by the input data can be displayed for each antenna as shown in Figure 4. This display contains both a tabular as well as a graphic display of all the antenna information in the input data set and hence allows for its easy verification. Hard copies of the complete set of patterns provide a complete record for later examination of the degree of approximation that had been used for each subsystem. The EMCCS module computes the coupling path for all antenna pairs for which frequency coincidence occurs. The associated coupling loss (Weinstock) can consist of free space, fuselage shading and edge diffraction losses depending on the trajectory of the geodesic path between antenna pairs. The EMI margin can then be evaluated. The user can examine all antenna pair combinations or restrict his examination to those combinations where in a pre-set value of EMI margin is exceeded. These combinations are available as a tabulated matrix that can be produced on a line printer.

6. APPRECIATING THE EMI MARGIN VALUES

The more complete quantization of the entries, T_{ij}, in the Interference Interaction Sample Space comes about when the actual EMI values are known. The EMI margin module allows the display of this data for each interacting antenna pair. Figure 5 shows a typical display. The upper left hand corner consists of a tabulation of all the component values that are used to arrive at the EMI margin value for the worst-case frequency of each transmitter harmonic. Central to the display, however, is the aircraft model with the antenna locations annotated and most importantly, the actual coupling path between the antennas shown as a distinguishing dotted line. The lower right-hand corner tabulates the antennas involved and identifies whether the coupling path lies in the direction of the main beam or sidelobe of each antenna. Note then the degree of appreciation of the modelling process that this display produces. It becomes natural to examine how closely the modelling represents the "real world" aircraft installation once the path can be visualized and the diffraction point for example, identified. Should the user wish to have a closer examination of the path detail, the close-up display illustrated in Figure 6 is available. The viewing angle can be changed at will in all these illustrations by simple mnemonic commands. Once more, hard copies of each set can provide a complete record of the analysis for later examination. As a whole, the set of displays and data provide both an overview and considerable insight into the interaction space elements that had heretofore not been available. A minimum set of ground and flight test frequencies can now be chosen with more confidence or design action focused on critical combinations. Tolerances on EMI margin values are not easy to assign. Path loss values are antenna location dependent. However a position tolerance study implies a recomputation of all interacting combinations with a new input data set for each new antenna location. Within AAPG this also can be done in an on-line interactive mode.

7. SHOULD THE ANTENNAS BE RE-LOCATED?

The re-location of aircraft antennas involves several physical as well as electromagnetic factors that can affect performance. Of course, relocation should never be considered without a thorough investigation of all these aspects. For purposes of EMC analysis alone, however, it is desirable to assess the extent to which the coupling loss is position-dependent. In many retrofit programs it is desirable to examine alternate antenna locations. The Antenna Position Input Module provides the capability to do this in a direct and easy way. In this module, when a specific subsystem antenna is called up, a templated display results which shows two calibrated views of the aircraft on which the present antenna position is coded. Its coordinate location is also tabulated at the bottom of the display as shown in Figure 7. A new antenna location can be selected by successively positioning the cursor in the desired location on the two views. The coordinates of the new location are immediately displayed as well as its coded location on the two aircraft views. The antenna can also be repositioned by specifying the numerical values of its new aircraft location (BL, WL, FS) or by a hybrid combination of cursor use and numerical entry. As soon as the location is acknowledged to be correct, a new page is displayed that lists the angular limits of the antenna pattern. These can be altered line-by-line. Once more the antenna pattern can be displayed as shown in Figure 4. Once the data is acknowledged as correct by the user a new antenna input file is created. The user exits from the GDMS via a "recompute" mode and the EMCCS immediately begins the total set of new interaction computations, which when complete, can once more be reexamined by the GDMS as described above. The new EMI margin and path loss values can now be evaluated. This process can be performed as often as necessary and with as many antennas as is desired, as long as the mass storage space is sufficient to hold the output information for each separate input data set.

The flexibility of this system has led to its use not only for tolerance and for trade-off analysis but also for important new applications.

8. CREATIVE NEW APPLICATIONS

The most extensive and varied use of AAPG to-date has been made at ECAC as described by Hodes and Widmer (6). Of particular interest is its use for Electromagnetic Radiation environment evaluations and definitions. The antenna gain at each receiver antenna location can be specified numerically in such a way that the resultant AAPG output is of power density at the antenna location. This has been used to define the total expected EMR environment at weapon stations by locating antennas at these respective locations. Such a probing can be carried out at any location that may be of interest on or near the aircraft.

Although helicopters do not lend themselves to the conventional nose-cone/cylindrical fuselage representation of the computer model, some can be approximated by cylinder/cone geometries with the cone facing aft. By careful specification of the antenna coordinates in order to transform them into values acceptable to the program, such helicopter geometries have indeed been analyzed.

The most recent comparison of AAPG predictions with aircraft test data is that reported by Hodes and Widmer (6). For an F-14 aircraft, AAPG correctly predicted 149 EMC interactions out of a 156 non-trivial ones. In one of these cases, AAPG failed to predict actual electromagnetic interference. This failure was apparently subsequently traced to an incorrectly specified interference threshold in the input data. The other six cases were "fail-safe" predictions, i.e., cases of EMI where actual electromagnetic compatibility (EMC) existed.

9. CONCLUSION

The power and flexibility of AAPG's interactive analysis and display capabilities provide the engineer with a rapid and straightforward way to carry out the complex task of EMC analysis and design in modern avionic systems. In addition to base-line EMC surveys, complex trade-off analysis can be carried out cost effectively and with new insight into EMI interactions. Studies of EMR environment are natural extensions of the primary uses of AAPG. EMC problems associated with the integration of new systems into existing platforms can be analyzed quickly and with a more complete appreciation of the associated coupling factors between systems.

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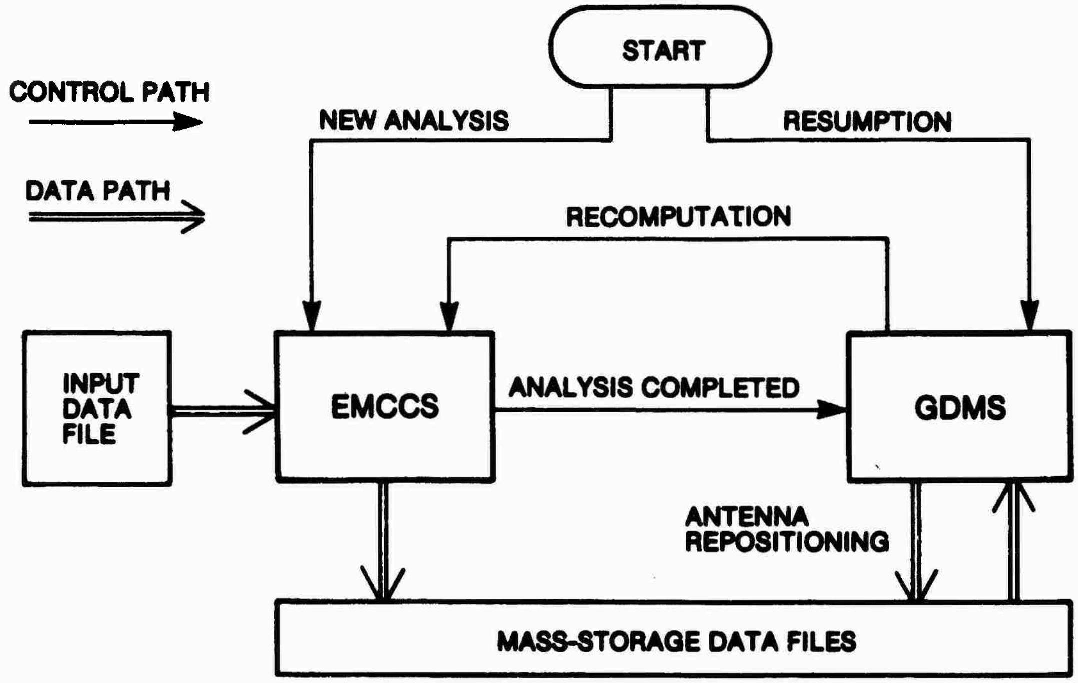


Fig. 1 Structure of AAPG

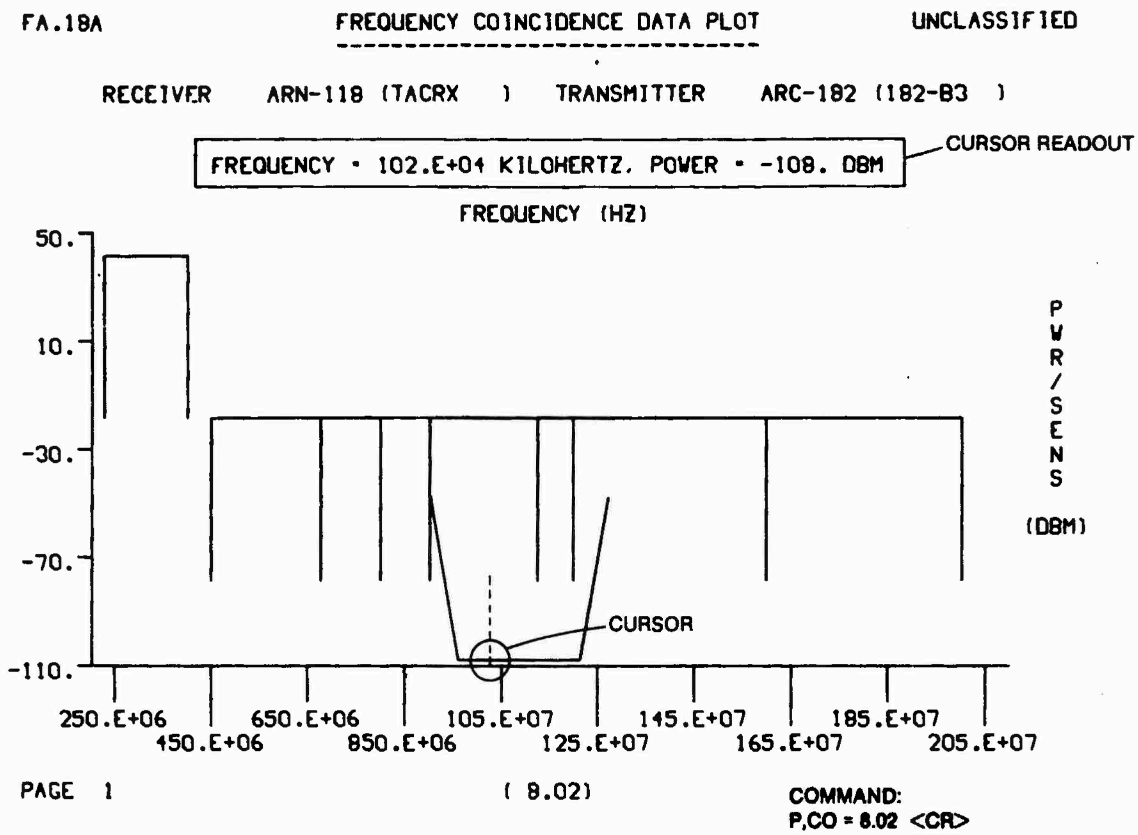


Fig. 2. Frequency Coincidence Display With Cursor

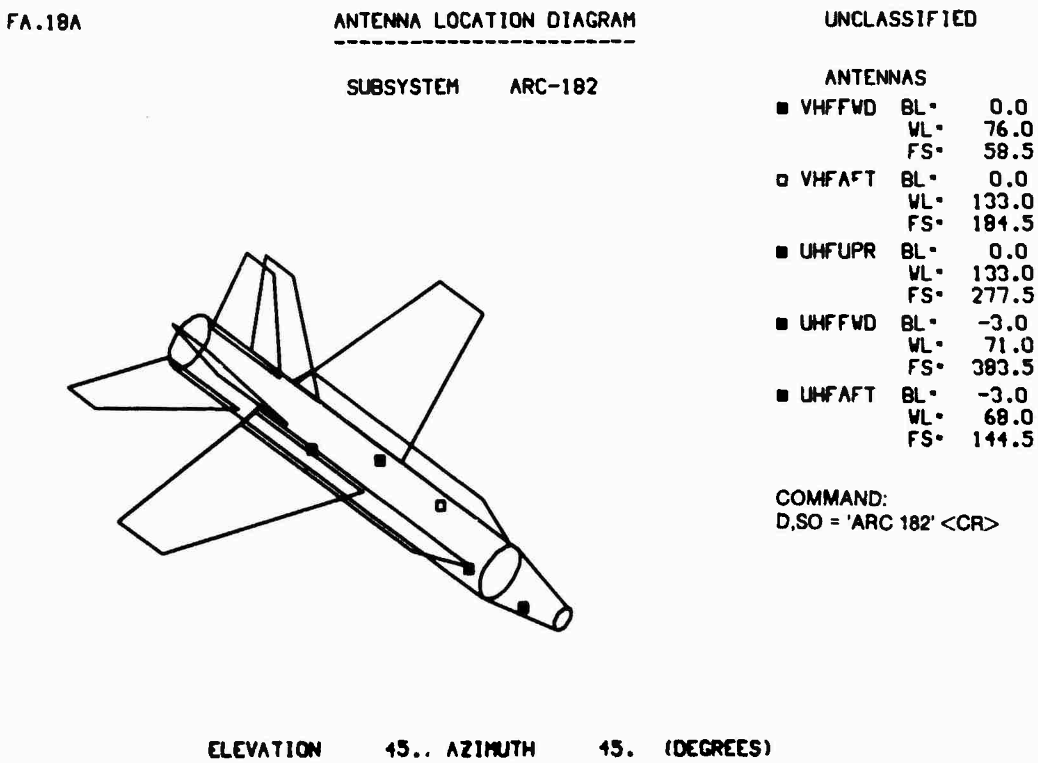


Fig. 3 Antenna Position Display

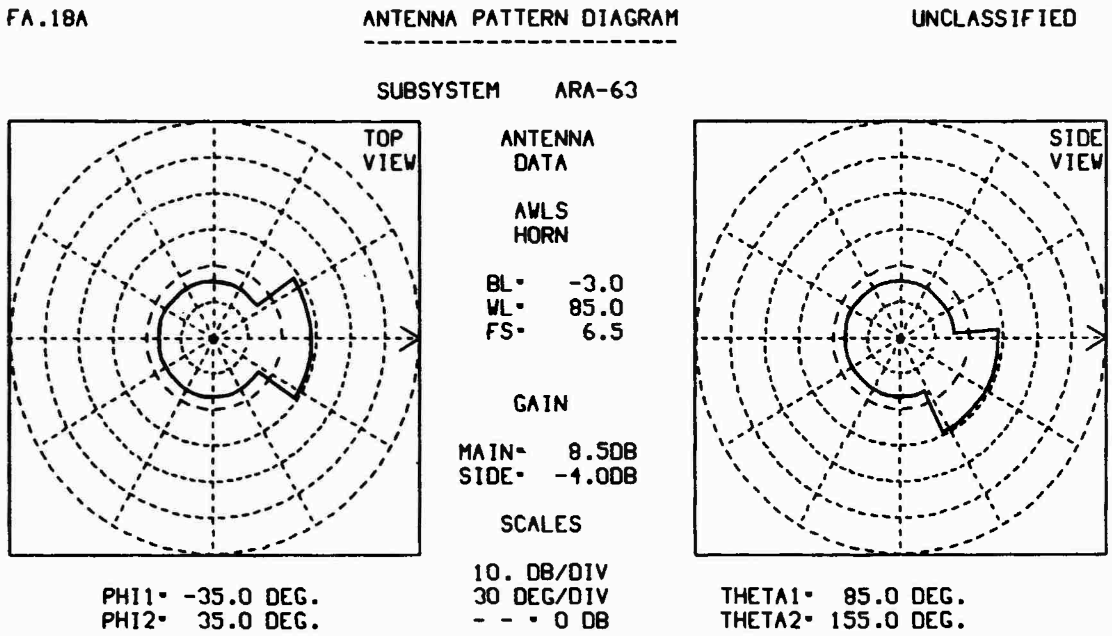
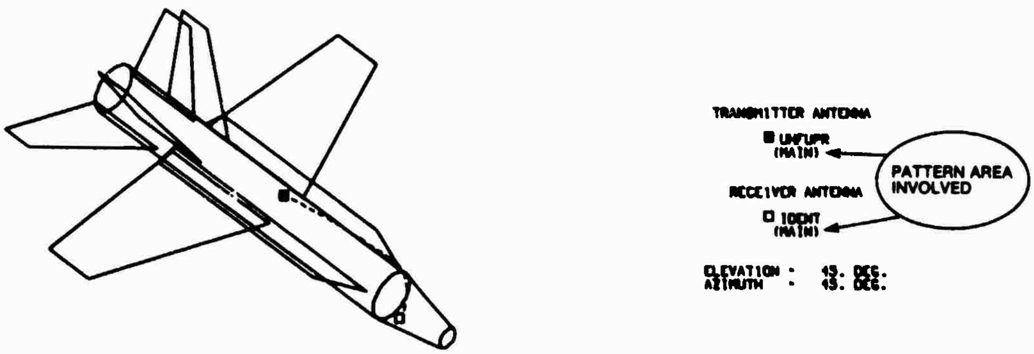


Fig. 4 Antenna Pattern Display

FA.18A ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION UNCLASSIFIED

TRANSMITTER ARC-182 (182-83) RECEIVER APX-100 (IFF-RX)

DESCRIPTION	HARMONIC NO 3 1.0 GHZ	HARMONIC NO 4 1.0 GHZ	HARMONIC NO 5 1.1 GHZ
TRANSMITTER POWER	-18.2	-18.2	-84.4
XMTR CABLE LOSSES	0.0	0.0	0.0
XMTR ANTENNA GAIN	2.1	2.1	2.1
TRANSMISSION LOSS	-48.4	-48.4	-49.1
SURFACE SHADING	-23.9	-23.9	-24.9
EDGE SHADING	-33.6	-33.6	-34.0
RCVR ANTENNA GAIN	2.1	[illegible]	2.1
RCVR CABLE LOSSES	0.0	0.0	0.0
RCVR SENSITIVITY	-95.0	-95.0	-15.0
EMI MARGIN	-24.9	-24.9	-173.2

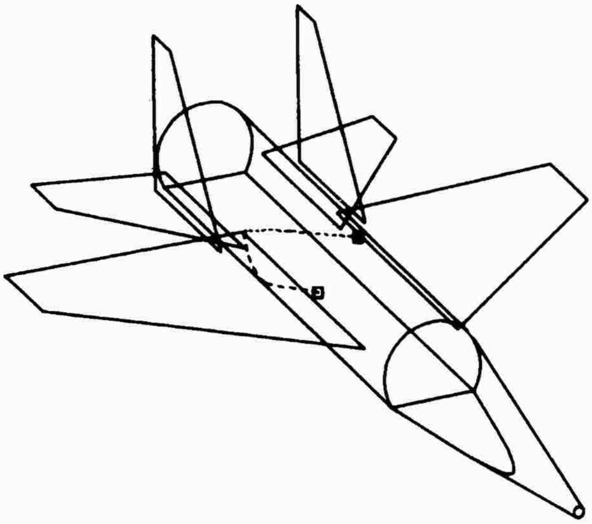


(3.01-00)

Fig. 5 EMI Margin Display

F-15 PROPAGATION PATH DISPLAY UNCLASSIFIED

RECEIVER	COMM	(UHFRX)	TRANSMITTER	VHF	(RTAT)
ANTENNA	UHFLO	(MAIN)	ANTENNA	37J3	(MAIN)



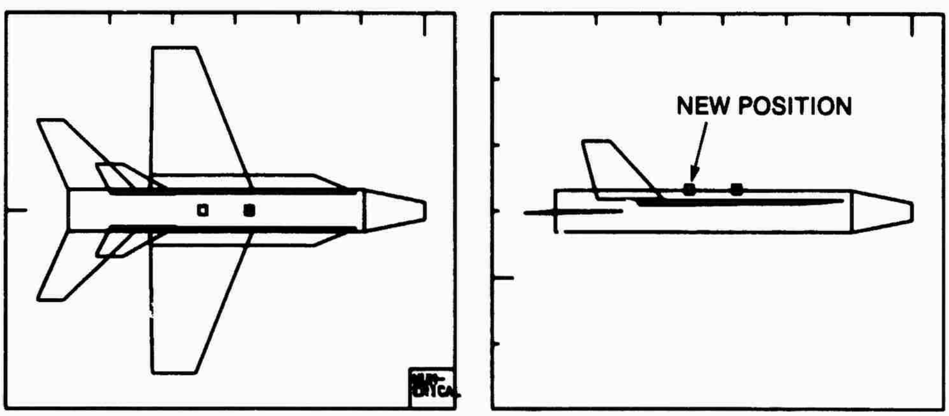
ELEVATION 25. AZIMUTH 25. (DEGREES)

(1.01-01)

Fig. 6 Closeup Of Coupling Path-Flat-Bottom A/C Model

FA.18A ANTENNA POSITION INPUT UNCLASSIFIED

SUBSYSTEM ARC-182 ANTENNA UHFUPR



POSITION	BUTT LINE	WATER LINE	FUSELAGE STATION
OLD	0.0	133.0	277.5
NEW	0.0	133.1	352.4

IF POSITION IS CORRECT ENTER 'OK'

Fig. 7 Antenna Position Input, Cursor Alone

DISCUSSION

D.Jaeger, Ge

(1) Do you have some information about the fault tolerance of this computer program; have you made a comparison between measurement and computer results?

(2) Does your program cover resonant effects of the structure which may be of interest for low frequency ranges?

Author's Reply

(1) The best information we have to date is that produced by engineers at the Electromagnetic Compatibility Center (ECAC) in Annapolis, Md. This is available in the last reference quoted in the proceedings paper.

(2) No. These are rag-optical techniques and cannot deal with resonance effects. However, with moment method techniques we have been able to detect these.

SUMMARY OF SESSION III
SYSTEM DEVELOPMENT CONCEPT

by

Dr G.H.Hunt
Session Chairman

From an overall point of view, the session can be assessed as generally successful, the papers being well presented and generating some well-informed discussions from the floor. Because of the diverse range of topics covered within the session, it is difficult to draw any specific technical conclusion. What, however, was properly made clear is that the closer integration of avionic equipments in modern aircraft requires that very considerable time, and that resources should be devoted to the systems integration task.

Paper 23 dealt with the experiments on the human factors aspects of the display system for a television guided lock-on missile for use against ground targets, such as will be employed by the Federal Republic of Germany. The work involved encompassed head-up displays, head-down displays, and helmet mounted displays.

Paper 24 outlined the software development environments over the last 20 years, using as examples aircraft developed by British Aerospace. The problems of rapid growth of computer requirements were discussed,and future British Aerospace activities to meet these problems were detailed.

Paper 25 described the Avionic Systems Demonstrator Rig at British Aerospace. This represents a complete aircraft system, linked to an advanced cockpit, appropriate to the next generation of tactical combat aircraft. The object of this exercise is to gain the experience necessary to reduce the development risk associated with rapid advances in technology.

Paper 26 outlined the development of communications and navigation identification (CNI) systems from the original concepts which were just a collection of individual equipments, through to a concept of an integrated CNI discussed in this paper, in which several receiver-transmitters are interfaced with a signal processor. Such a system can be made adaptive, with reconfiguration automatically carried out following failure.

Paper 27 originated from the premise that the choice of a weapon system must be determined by the trade-offs between the effectiveness of the weapons and the vulnerability of the delivering-aircraft to ground forces. The paper describes a computerised technique to assist in assessing the vulnerability of specific delivery tactics. A digitised model of real terrain is used, and, to reduce the computational load, realistic profiles are developed from a series of flight segments. Intervisibility algorithms are used in assessing aircraft vulnerability.

Colour cathode ray tube displays are now approaching the stage of allowing their use in high ambient light level cockpits. Paper 28 described and discussed current technology, i.e. beam penetron and shadow mask, raster and stroke writing and then continued with a review of a five-phase programme of assessment and demonstration of advanced technology displays.

The assessment of the value of complex systems is a difficult and very important task. Paper 29 described an approach, based on weighting the individual attributes of the system. An example of the application of the technique to a complex avionic system for a tactical fighter aircraft was described.

Paper 30 described the research programme using the F-16 aircraft to develop and flight-validate advanced technologies to improve fighter lethality and survivability. The digital flight control system is the core technology, providing 6-degree of freedom decoupled aircraft control, being developed in the present phase 1 activities. Phase 2 will study automated manoeuvring attack, in which the digital flight control system will be coupled to the fire control system.

Paper 31 was a wide ranging paper, covering most of the avionics and weapon management aspects of future aircraft, although the main concentration was on the weapon. A rig for integration and test of weapon delivery systems was described. A concept for future weapon delivery system was discussed, which included such aspects as automatic maintenance predictions, GPS/ITDS/IN navigation systems, etc.

Paper 32 referred to a requirement to identify preferred software tools for the in-service phase of Tornado, for support of major avionic refits in general, and for the support of the description and the development of future aircraft

It was considered that no completely satisfactory tool existed at the time, and hence to meet this requirement CADAS was developed. This is a computer aided design tool, designed to make maximum use of commercially available operating systems.

Paper 33 dealt with the need to study EMC problems in weapon systems. The paper emphasized the need to consider the EMC aspects from the very beginning of a project, and plan manning levels, work programmes, etc., accordingly. Often, the primary objectives of structural, mechanical, and electrical design will be in direct conflict with good EMC practices. The management of EMC must be undertaken by senior managers, familiar with the problems. The programme must begin in the planning stage, proceed through analytical studies and evaluation tests to prove the design concepts, and finish with the testing of subsystems, and later complete systems.

Paper 34, the final paper of this session, described a programme initiated in 1975 aimed at providing guidance on how to design avionic systems for the 1980s. Design considerations included cost, reliability, and maintainability. The work led to the building of a demonstration system in a Cessna 402 twin-engined general aviation aircraft.

THE LOCK-ON-BEFORE-LAUNCH WEAPON DELIVERY AND DISPLAY/CONTROL CONSIDERATION

by

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1. INTRODUCTION

The deployment of combat aircraft against stationary and mobile ground targets that are protected by air defence, means a very high danger for man and machine. In order to eliminate this danger, it is planned to develop and to employ weapons such as low altitude dispensers or terminal-guided submunition (e.g. WASP) against armoured mobile targets, Short-Range-Anti-Radiation-Missiles (SRARM) and MAVERICK against stationary one's.

For successful attacks against ground targets, the Federal Republic of Germany intends to procure TV-guided missiles of the type AN/AGM-65B MAVERICK. This missile is guided by a TV-seeker head with ~~a~~ scene magnification. The weapon delivery is based on LOCK-ON-BEFORE-LAUNCH. The time between target recognition and launch is very tight, so that the weapon aiming procedure has to be as efficient as possible. ~~The following~~ describes investigations to provide basic test data to assess different methods of target acquisition and missile seeker aiming and lock-on. In addition, ~~to that~~ the pilot workload with different controls and displays ~~was to be~~ assessed and methods of reduction derived. ~~Further to this,~~ different weapon information and Weapon-Video-Display-Systems and their advantages and disadvantages were investigated. The accuracy and speed of weapon aiming should be especially evaluated.

The criteria for ~~the~~ choice of a display system are:

- pilot's workload,
- reaction time to lock-on,
- possibilities of multiple target combat in the first attack.

2. MISSION

The following gives a short description of an air-to-ground mission of an one-seated combat aircraft with a TV-guided MAVERICK. The ASM's are delivered against two classes of targets:

- primary: stationary targets
  bridges, railways, command posts, storage depots
- secondary: mobile targets of opportunity
  groups of tanks, mobile AAA

The sequence of weapon delivery is shown in Fig. 1. This is:

1. target recognition through HUD
2. identification and classification
3. pointing the aircraft at the target
4. moving the eyes from HUD to weapon's display with adaption and accomodation
5. target recognition with weapon's display
6. changing of video-polarity (if necessary)
7. putting the track-gates onto the target
8. lock-on-test
9. weapon launch
10. egress

These tasks done by the pilot take a time of 6 seconds (minimum) to 12 seconds (maximum) for the first weapon. The distance the aircraft has moved within this time is illustrated with a velocity of 200 m/s and 300 m/s respectively. Fig. 2 shows the horizontal situation for an attack against a column of tanks protected by ZSU-23-4.

Two special points can be highlighted. The first marks the place where the targets have been recognized and identified by the pilot. This range depends on several parameters e.g. daylight, meteorological limitations. A good number is 4 km/2,2 NM (sometimes 6 km/ 3,2 NM). The second point is characterized by the egress flight path to avoid the lethal radius of the air defence site. The figure shows a turn radius for 3 g's. Weapons can be delivered within a range limited by theses two points. As seen from Fig. 2, the range is approximately 1,9 km/1 NM. This leaves the pilot 9,5 seconds for weapon delivery when flying 200 m/s or 390 kts. The weapon delivery takes a time between 5,3 seconds and 8,0 seconds after recognition and identification.

3. DISPLAY CANDIDATES

The remaining time should be uses as well as possible. One aspect here is the best display system. A raster display system has to be integrated into the cockpit area in order to present the weapons video signal to the pilot (Fig. 3). Four different candidates are available with different capabilities:

1. Panel-Mounted Head Down Display (HUD)

2. Virtual Image Display (VID)

3. Raster Head-Up Display (HUD)

4. Helmet Mounted Display (HMD) (not investigated in laborartory experiments)

When integrating a HDD the cockpit panel has to be redesigned and exchanged in existing aircrafts. On the other hand this type of display can be used as a multi-function-display.

Integrating a VID causes few problems especially in existing aircrafts. One aspect, however, is that a VID reduces the visual field.

The weapon aiming with a HUD raises problems concerning harmonization between both lines of sight (weapon and HUD) and problems concerning the pilot's physiology.

To slew the seeker head with a HMD before 1 eye leaving the other free for external viewing seems to be a successful solution. Problems concerning the different images magnifications have to be considered.

4. WEAPON AIMING WITH HUD

The procedure to aim the seeker head at the target by using a HUD is greatly different to that used with other displays. The visibility through the HUD is overlaid with the weapon video. Special problems occur which are discussed below.

The target has to be detected and identified through the HUD. The view through the HUD should not be affected at all. On the other hand the TV-video produced by the seeker head is displayed in raster. Now the pilot's full concentration should be directed to observe the video image and the view to the outside world should not be possible. A reasonable compromise has to be found between these two extreme requirements which contradict each other.

The HUD-combiners mostly used nowadays consist of a mirror with a typical transmission coefficient of approximately 70%. The typical reflectivity is approximately 25% which means that 75% of the brightness of the CRT is lost. The remaining optical system has an efficiency factor of about 60 - 80%. So the total transmission of light in the optical path of the CRT of a conventional HUD is about 15 - 20%. The brightness of symbols must be approximately 1600 ftL to be read in worst case cockpit conditions. This means that the brightness of the CRT must be 8000 - 10700 ftL according to the above-mentioned transmission. Fig. 4 shows a comparison of transmission and reflectivity between reflection and defraction HUD.

Taking a wide angle HUD (WHUD) the brightness is about 1200 ftL. This is in conjunction with a contrast ratio of 1.16 suffici[illegible] in Central Europe with ambient light of approximately 7500 ftL on a sunny, light cloudy day.

Resolution

Several investigations have shown that the following requirements have to be met if brightness with respect to ambient light is sufficient:

- 8 lines-hight of symbols for recognition of alphanumeric and geometric symbols
- more than 10 lines for a 90% identification of alphanumeric
- more than 16 lines for a 99% identification of geometric symbols and images

Video-Presentation

o Geometry

The fade-in of the weapon's video into HUD is possible with

- rectangular
- quadratic or
- circular

formats. A quadratic or circular format is preferred in accordance with the other cockpit displays. Since the video format is square (i.e. 500 lines by 500 columns), so the square format is therefore most appropriate. On the other hand the information of most interest is in a circular area around the center. For this a circular format was preferred in the laboratory examinations.

Video-Display Location

During ground attack the pilot's view is mostly below the aircraft datum line (ADL). The lines of sight of the weapons are depressed of about 2° relativ to ADL. The real FOV (2,5° x 2,5°) of the missile is shown in Fig. 5 by the small square. On the other hand the video information should be presented as large as possible to relocate the target as well as possible (large square, dashed). From this it becomes clear that there never will be agreement between the two formats. The video image has to be presented at a location where an observation of both target areas (actual through HUD; image in HUD) is undisturbed.

Fig. 6 shows several proposals to place the video within the HUD area of a conventional HUD and a WHUD. The loss of information between quadratic and circular formats of approxima- 20% is shown in Fig. 7. Fig. 8 shows the locations of video on a WHUD. Only when the is located in the center area below the ADL the scales for velocity and altitude can be presented in addition to the digital display format. So this area is preferred.

The laboratory examination furnished the following results:

- If only a part of the video is presented (mini-raster) the test pilots could establish no correlation between view out of the cockpit and the display video image.

- When presenting the whole video information in the center area of the HUD the test pilots could relocate the targets.

- Only when the video was very bright the background did not disturb the aiming process.

5. LABORATORY EXPERIMENTS

The goal of the laboratory experiments was to provide basic test data to assess different methods of target acquisition and missile seeker aiming and lock-on. Different weapon information and weapon-video-display systems, their advantages and disadvantages were investigated. Accuracy and speed of a weapon aiming was evaluated.

For the realization of the experiments flight trajectories have been produced in a terrain/flight simulator and with some Alpha Jets in real flight. The flight path was fixed (autopilot function: attitude hold) and could not be modified by the test pilots. This was done in order to eliminate the handling qualities of the aircraft from the aiming procedure and to concentrate the testpilot's attention to the displays and controls.

Six flight trajectories were presented against five tactical targets:

1. industrial site
2. bridge over river (approach from the hill side)
3. bridge over river (approach into a valley)
4. tanks in assembly area
5. cluster of shelters on an airbase area
6. tanks for air defence on an airbase area

The investigations have shown that target No. 1 could be detected very well because of their prominence. The targets No. 2 and 3 were difficult to detect because there was only little contrast with the surrounding. Target No. 4 was the most difficult one because the tanks were masked. Targets No. 5 and 6 were fairly easy to detect because the shelters had a cleare structure and the tanks provided a good contrast.

The procedure for weapon delivery was the following (Fig. 9):

1 Start the flight from the top of the pull-up manoeuvre; aircraft pointed at the target; dive angle -10°; slant range 6 km/3.2 NM; velocity 200 m/s/390 kts

2 UNCAGE the seeker head when the target is recognized on the display

3 Slewing the seeker head onto the designated target

4 Activating the lock-on algorithm

5 Weapon release

6 Next weapon, see 2

The times for

- target recognition (t_1)
- lock-on (t_2)
- weapon launch (t_3*)

were recorded and interpreted. In addition the testpilots had to fill in a questionnaire to give their personal opinion concerning efficiency and workload with the different displays.

6. RESULTS

In addition to the subjective impression the objective criteria for valuation were analysed, like duration for recognition/lock-on/launch and the number of weapons delivered. 16 testpilots carried out 185 approaches with

HDD = 60 / 32%

VID = 62 / 34%

HUD = 63 / 34%

From now on all numbers are normalized to a basic figure. A total number of 100 missiles had been "delivered":

HDD = 44%

VID = 31%

HUD = 25%

No missile could be launched successfully within 32 approaches. This is

HDD = 22%

VID = 32%

HUD = 30%

One or more missiles could be launched successfully with 68 approaches:

HDD = 38%

VID = 32%

HUD = 30%

Two or three (max.) missiles could be launched successfully with 42 approaches:

HDD = 44%

VID = 30%

HUD = 26%

Three missiles could be launched successfully with 25 approaches:

HDD = 61%

VID = 28%

HUD = 11%

Taking the average for all types of displays and all targets gives a number of successfully launched missiles with one approach

HDD = 1,82

VID = 1,23

HUD = 1,00

The absolute figures depend on several effects of mostly subjective nature. In order to get a better overview over the results, the number of missiles and the different durations are compared among each other. So, the results for VID are arbitrarily set to 1. The frequency for the number of delivered missiles are shown in Fig. 10 with this basis. This proves the superiority of HDD with a result of 48% better than VID and 82% better than HUD. The difference between VID and HUD is not so dramatic (23%).

The results gained from the number of missiles can be proved by analyzing the durations. The average time to recognize the target for the first time is (normalized)

t_{11}(total) = 1 sec

This means for the different displays

HDD = 0,89 sec

VID = 0,99 sec

HUD = 1,14 sec

To recognize the target for the second missile is

t_{12}(total) = 0,24 sec
HDD = 0,22 sec
VID = 0,25 sec
HUD = 0,26 sec

and for the third time

t_{13}(total) = 0,19 sec
HDD = 0,16 sec
VID = 0,24 sec
HUD = 0,18 sec

These results make clear that the time to recognize the target the first time is the smallest for HDD. VID is approximately 10% and HUD 25% ill towards HDD. VID and HUD are fairly equivalent for the second recognition. HUD is 13% better.

The time between recognition and launch is the duration of weapon aiming. It is different for the first, second and third missile because of the learning effects.

For the first missile it took

t_{21}(total) = 2,06 sec
HDD = 1,69 sec
VID = 2,01 sec
HUD = 2,48 sec

The time for aiming the second missile is

t_{22}(total) = 0,94 sec
HDD = 0,98 sec
VID = 0,82 sec
HUD = 1,01 sec

In this case VID is the best one with a saving of time of 19% towards HDD and 22% towards HUD.

The time to aim the third missile is still smaller.

t_{23}(total) = 0,76 sec
HDD = 0,68 sec
VID = 0,70 sec
HUD = 0,90 sec

Finally the total time for the delivery of the first missile is considered (Fig. 11). The average time over all displays and all approaches is

t (total) = 3,11 sec

and for the three types

HDD = 2,62 sec

VID = 3,16 sec

HUD = 3,64 sec

The overall saving of time is 17% towards VID and 28% towards HUD.

To summarize the results Fig. 12 shows the three different aspects that came into the valuation for the effectiveness of a display system

- o number of successfully delivered missiles
- o time (saving of time resp.) for weapon delivery
- o pilot's judgements concerning effectiveness

All three criteria indicate the same tendency.

The testpilots gave the HDD the first rank. This display scored the most successfully delivered missiles and led to the greatest amount in saving time. Fig. 13 summarizes the most important results.

Three facts can be stated to comprise the results:

1. The superiority of the HDD is evident.
2. Weapon aiming with a raster HUD is possible.
3. There is only a little chance for weapon delivery of LOBL-missiles in a one seated combat aircraft in Central Europe without support.

The improvement of weapon delivery results in supporting the pilot during

- target recognition and
- weapon aiming .

The following outlines are subject to further investigations and no results are available yet.

Target recognition

The launch range of LOBL-missiles is restricted by the capabilities of human eyes because the pilot has to detect, identify and classify the target through HUD. The stand-off capability of the weapon could be used to increase the effectiveness of the attack. For this the pilot has to be supported by special computation and/or additional sensors with a wide field-of-view (FOV). This could either be a FLIR- or a RADAR-System. Hot points can be detected in a FLIR image. These can be examined for the presents of simple features like length, width, contrast, movement etc. /4/, to classify the targets. These targets shall be marked in a special manner (e.g. flashing). The pilot steers the aircraft so that the symbol will be within the FOV of the missile displayed in the HUD. Now he is sure to refind the target on the weapon's display. The idea is that although the pilot did not see the target in the HUD -only the symbol- that he can use the magnified image of the weapon seeker head to increase detection range.

Weapon aiming

A dramatic improvement of ground attack can be expected by reducing the time for weapon aiming. A reduction can be accomplished if not the pilot but an intelligent electronic slews the seeker head to bring the target into the weapon's tracking area. For this purpose the pilot designates the target to be attacked on the weapons display by pressing his finger onto the target area on the display. An electronic device finds out where he has pointed. Two angles (azimuth and elevation) relative to the middle of the display are evaluated. The seeker head is now moved to zero these two angles and makes lock-on. The pilot has to examine whether the seeker has locked on to the designated target.

The advantage of this procedure is that the pilot looks into the cockpit to refind the target only. After designation he can direct his attention to other things, e.g. to keep the flight trajectory or observe the threat. Since nulling of the two angles can be achieved automatically faster than the pilot can do it himself the time for weapon aiming will be reduced.

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LIST OF ABBREVIATIONS

ADL	Aircraft Datum Line
ASM	Air to Surface Missile
FOV	Field of View
HDD	Head Down Display
HMD	Helmet Mounted Display
HUD	Head Up Display
LOBL	Lock On Before Launch
SRARM	Short Range Anti Radiation Missile
VID	Virtual Image Display
WHUD	Wide angle Head Up Display

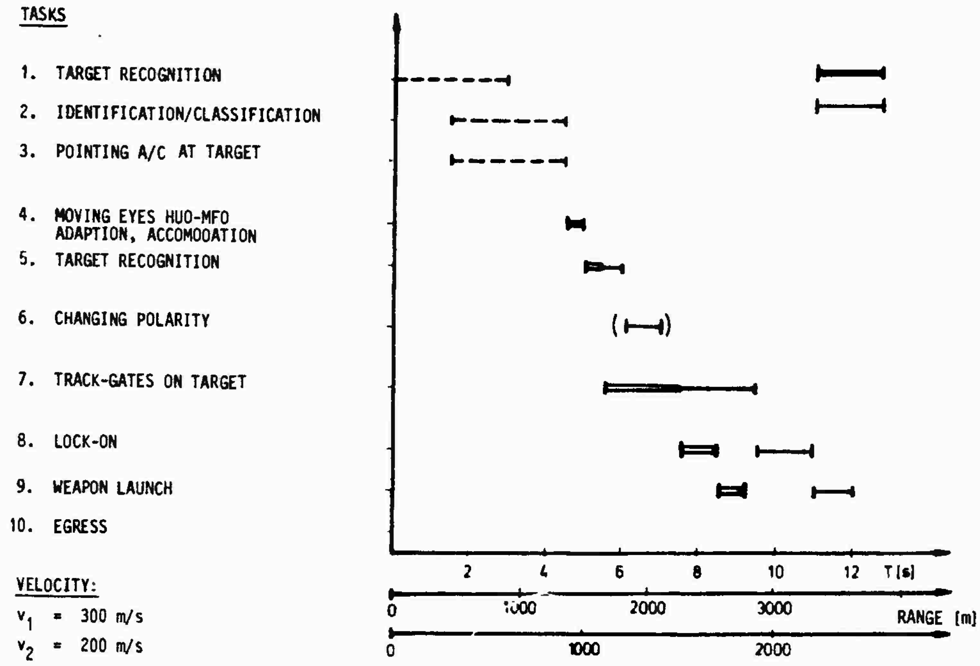

Fig. 1: TIME SCHEDULE FOR ASM-DELIVERY WITH LOBL-MISSILES

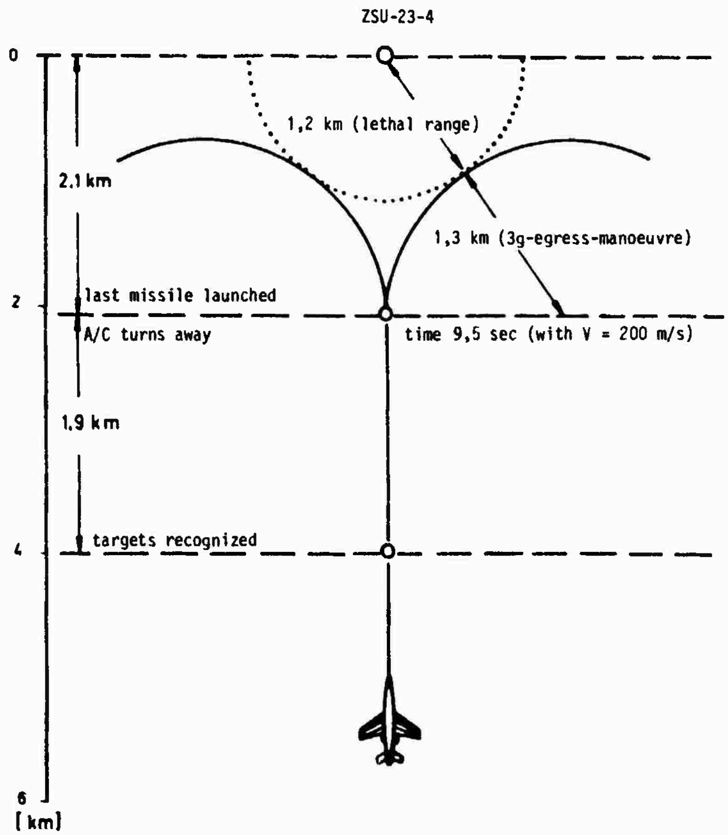

Fig. 2: ATTACK AGAINST TARGET PROTECTED BY ZSU-23-4

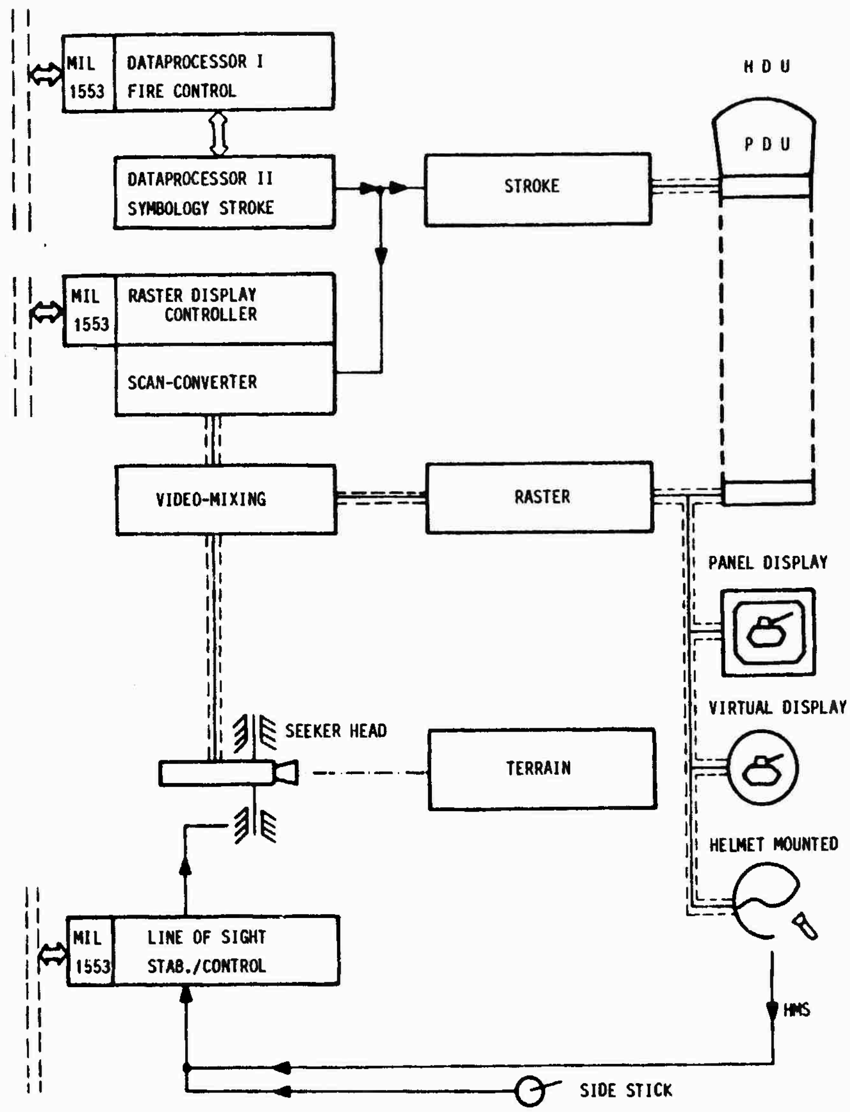

Fig. 3: LABORATORY SYSTEM FOR WEAPON DELIVERY (SINGLE SEAT)

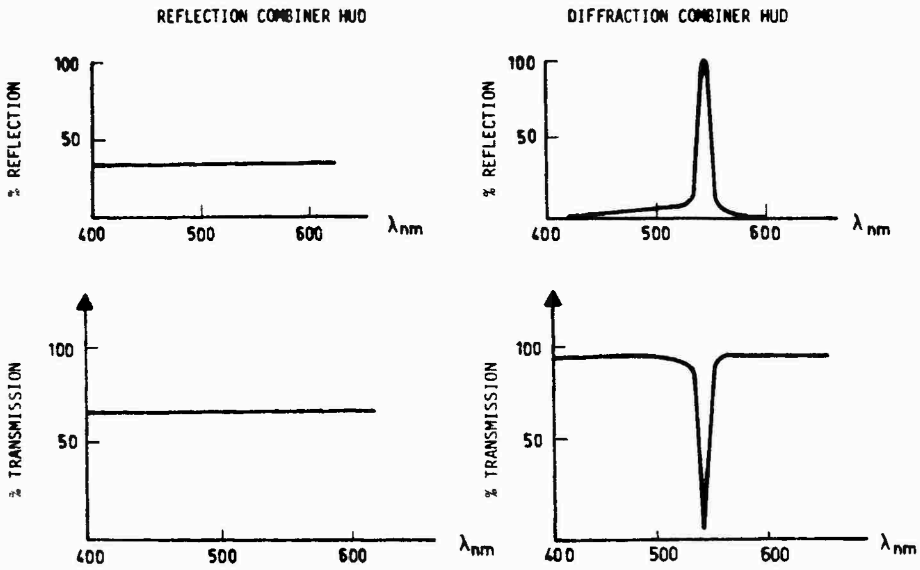

Fig. 4: COMPARISON OF REFLECTION AND DEFRACTION

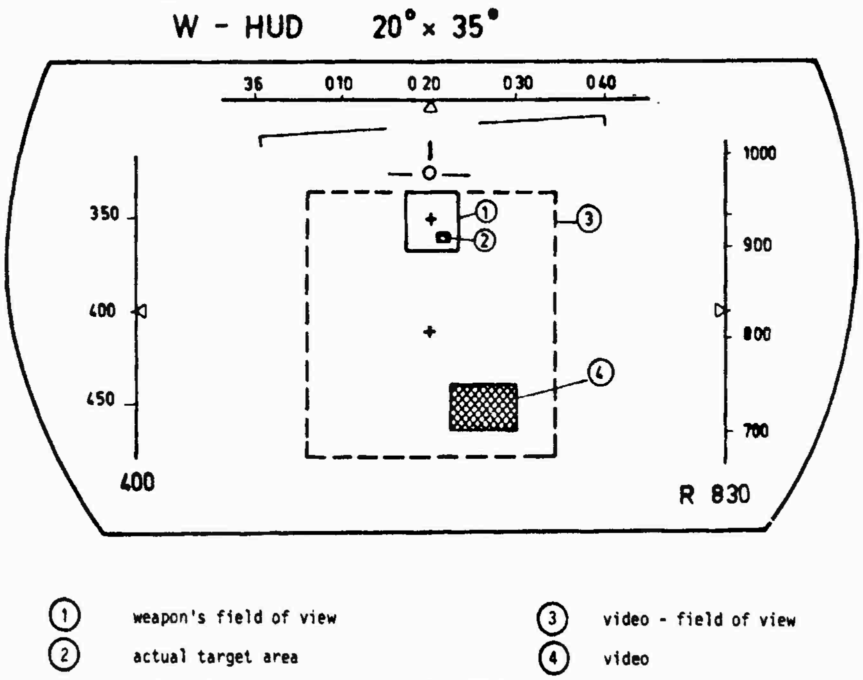

Fig. 5: WEAPON'S AND VIDEO FIELD OF VIEW

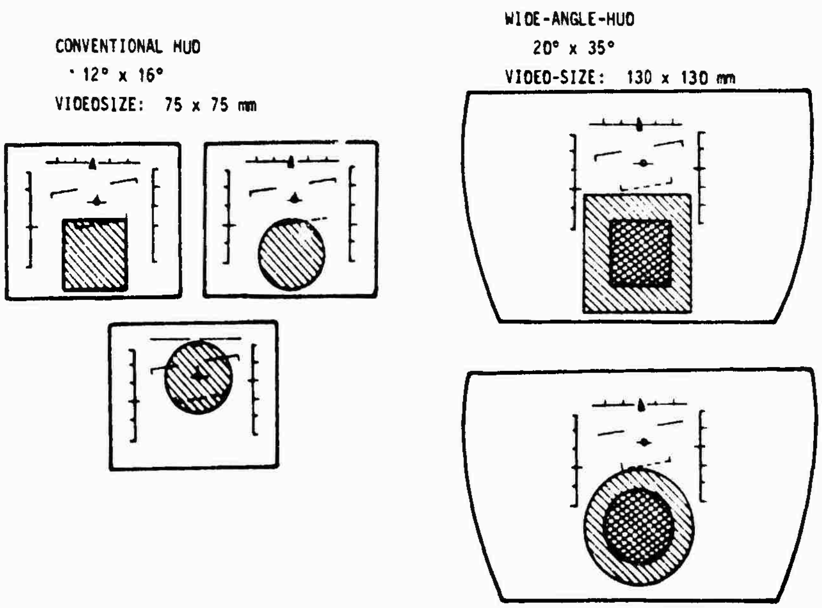

Fig. 6: LOCATIONS FOR VIDEO IN DIFFERENT HUD-SYSTEMS

WIDE-ANGLE-HUD
20° x 35°

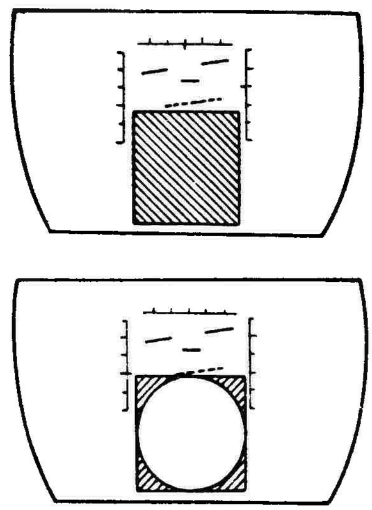

Fig. 7: LOSS OF INFORMATION

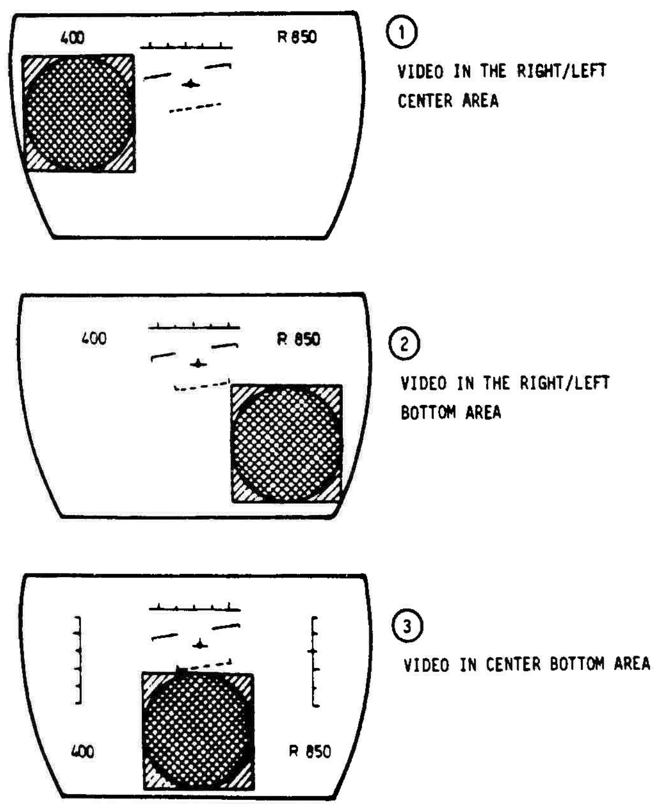

Fig. 8: LOCATIONS FOR VIDEO-PRESENTATION

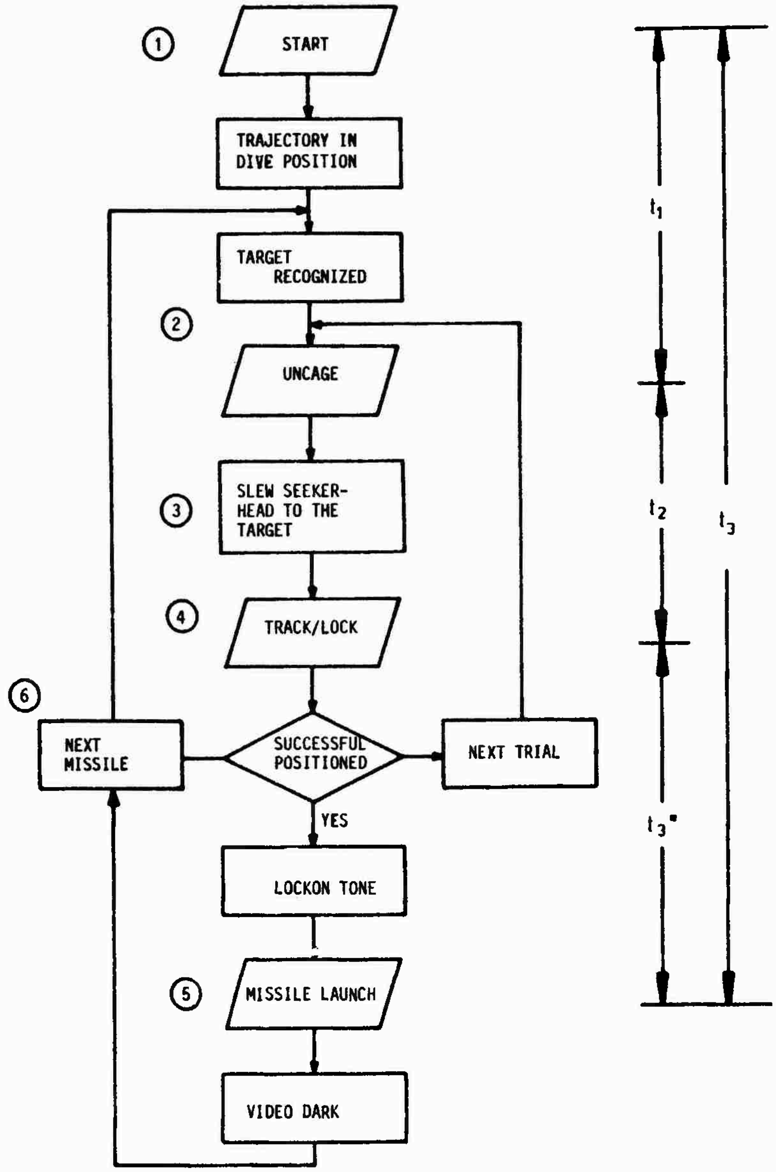

Fig. 9: TEST PROCEDURE

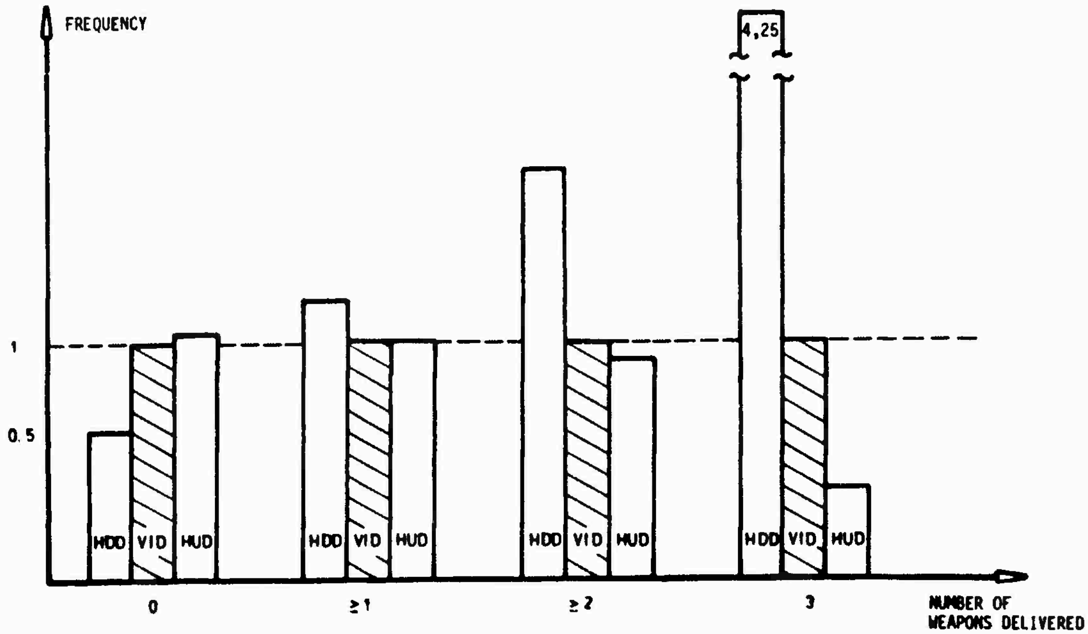

Fig. 10: FREQUENCY

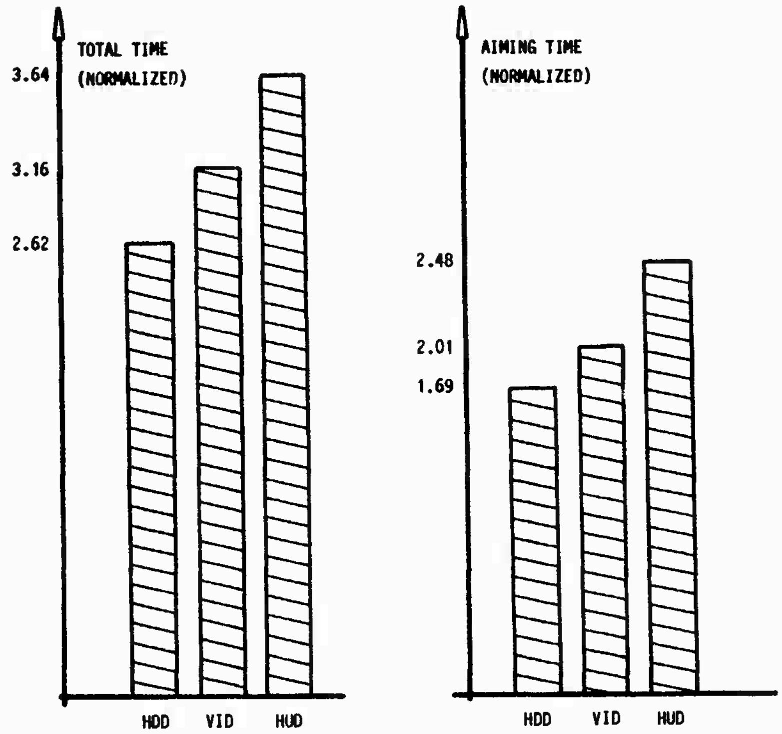

Fig. 11: MEANVALUE OF TOTAL/AIMING-TIME

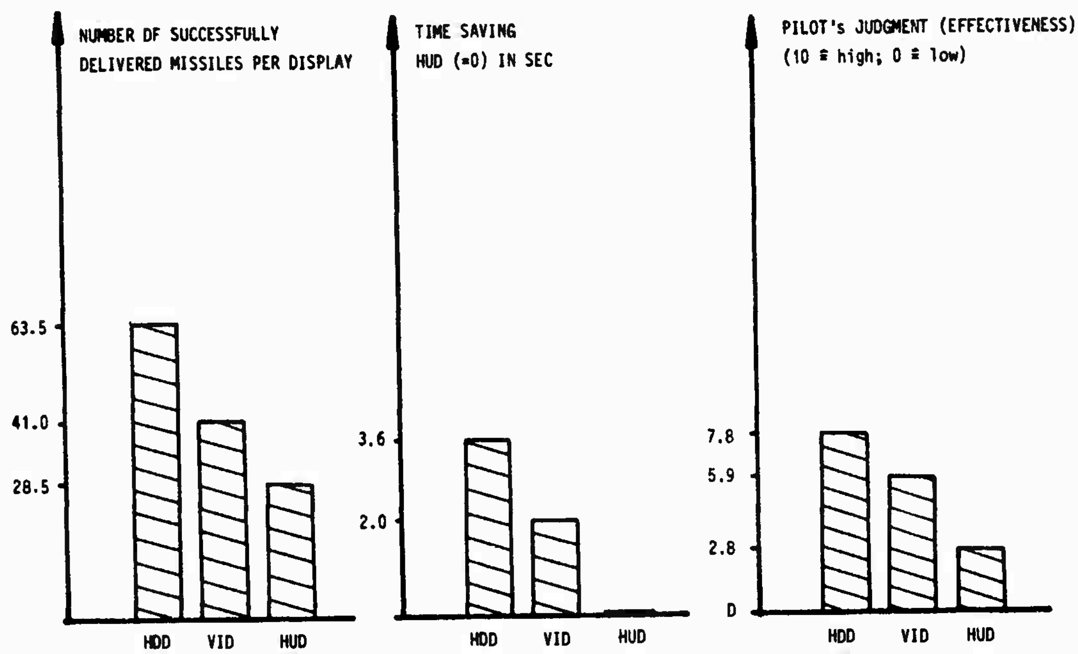

Fig. 12: RESULTS/SUMMARY

1. Pilot's judgment about effectiveness

HIGH	:	HDD
MEDIUM	:	VID
LOW	:	HUD

2. Number of successfully "delivered" missiles

	HDD	VID	HUD
Number of missiles in 1 attack	1.82	1.23	1.0
No missiles delivered	13	22	25
1 or more missiles	47	40	38
2 or more missiles	34	28	20
3 missiles	28	13	5

3. Duration

for relocation	HDD	VID	HUD
1. missile	3.06	3.40	3.91
2. missile	0.75	0.86	0.9
3. missile	0.56	0.82	0.61
aiming time			
1. missile	5.79	6.87	8.48
2. missile	3.35	2.82	3.45
3. missile	2.34	2.4	3.08
total time for 1 missile	8.79	10.82	12,46

Fig. 13: SUMMARY OF RESULTS

DISCUSSION

G.Hunt, UK

Are the performance advantages shown for the Head-Up Display expected to be valid in a more realistic experiment in which vibration was present and the pilot was performing a real flying task?

Author's Reply

Also in real flight tests we expect that weapon aiming will be possible with HUD. But some problems have to be solved, especially concerning (1) brightness of the video image; (2) pilot's training to overcome physiological burdens.

W.H.Vogl, Ge

The method that the pilot selects his target with the fingertip at the display surface, sounds certainly attractive. Did you investigate whether the pilot will be able to bring his finger sufficiently close to the target point, under dynamic high g-load conditions in the cockpit as they might occur in TF manoeuvring/target approach? Can you provide us with results of such investigations?

Author's Reply

For precise weapon aiming and lock-on of Lock-on-before-launch-weapon in air-to-ground engagement the pilot has to leave TF-flight, pop up and dive to the target. On this dive there won't be great g-manoeuvres.

CASCADE : A DESIGN ENVIRONMENT FOR FUTURE AVIONIC SYSTEMS

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SUMMARY

Current trends in computing hardware technology are leading to a dramatic increase in the processing capability of avionic systems. When viewed in parallel with international efforts to standardise on both computing elements and languages, there is an opportunity to make similar advances in the environment in which systems can be designed.

The design and development environment for software has grown from the basic needs of assembler to the wider requirements of higher order languages. ~~The~~ use of the latter has also witnessed a growing, but disparate, use of tools associated with the design process. Language standardisation has presented the opportunity to produce powerful software development environments. In the future,

The future poses significant challenges in that it will be difficult to satisfy the growth in computing capacity and complexity without at least ten-fold improvements in productivity. ~~Also~~, although the eventual aim is a single higher order language, the ~~project~~ route towards this ideal will still require the support of several languages.

Integrity and cost requirements will dictate the introduction of formal verification techniques to all levels of design and implementation. The use of VLSI/VHSIC technology and beyond will allow the designer to specify components and ~~hence~~ the design environment should be integrated with relevant CAD tools.

These prospects are discussed and illustrated using a model of a Comprehensive Avionic System Computing Analysis and Design Environment (CASCADE).

Those features of CASCADE which exist today are described and its progress is charted in the medium and long term.

INTRODUCTION

Of all modern technologies the one that continues to amaze us with its relentless progress in terms of density and performance is that which belongs to the design and manufacture of digital systems. The trends experienced over the last decade seek to repeat themselves over the next ten years and in doing so will cause us to continually re-examine the way in which we apply the technology. By implication this will also cause us to establish how we make maximum use of the technology in whatever applications are considered.

Comprehensive reviews of the state of the art abound and there have also been some very useful predictive papers discussing not only digital technology trends but also the impact on the design process (1). Taking a parochial view one can chart the progress over sucessive aircraft projects that have involved the Warton Division of British Aerospace over the last 25 years and in particular the comparison of several generations of electronics associated with computing on the aeroplane.

Fig. (1) treats this as a "Computing Cube" where trends are shown for both power and cost. The power function is expressed as:

$$\frac{\text{Speed in operations per/sec x Memory size in bits}}{\text{Volume in cuins}}$$

and shows a trend of about two orders of magnitude improvement per decade. A mid seventies data point is qualified as a single airborne computing centre capable of .05 MIP and with 0.15 MBITS of memory. A late 1990's point could consist of several such computing centres each capable of 3 MIPS with 10 MBITS of memory.

Despite this improvement the relative cost of the unit volume of computing is falling at about an order of magnitude per decade.

These locally experienced trends confirm the more general ones attributed to the technology and there is both a commercial and military commitment to maintaining them. The commercially based VLSI programme both in Japan and the United States is complemented by the VHSIC and VHPIC programmes in the U.S. and United Kingdom respectively. There may be varying degrees of emphasis between the two domains but the consequence will be the same with massive computing power becoming available.

It would be foolish to assume that we will not wish to fully exploit such computing power in avionic systems and again experience shows us that the availability of performance has been a limiting factor in successive projects. This experience, of course, is not limited to the avionic fraternity.

However, to fully exploit this growth in computing power we will almost certainly have to venture into computing architectures not to be found in the avionic systems of today. For example, architectures which will support and make use of multiple processors yielding greatly increased computational capacity through parallelism with fully distributed rather than federated control. This degree of parallelism will be capable of being realised at the chip rather than the board level and in doing so will necessitate the ability to specify integrated circuits which are tailored to particular applications but made up from general purpose computing elements.

These ideas will be discussed in more detail in later sections but it is believed that we must be considering the environment in which such systems will be developed. It is suggested that the greatest challenge to be faced will be the nature of the design problems themselves along with the methods and tools we need to solve them. Such an environment should be as comprehensive as possible, supporting not only the detailed design phase but also all other relevant parts of the product lifecycle.

In order to minimise duplication of facilities and in order to span several generations of technology it should be capable of supporting not only software, embracing several languages, but also the specification and design of hardware of the kind outlined above.

The computing to be found in future avionic systems will need considerably more effort invested in design and analysis at the expense of testing as the complexity of systems will make comprehensive testing impossible. This tendency for proof in design rather than by test will accelerate the move towards increased investment in the earlier phases of the product lifecycle. A model environment to support such a trend is discussed here termed CASCADE or a Comprehensive Avionic System Computing Analysis and Design Environment.

HISTORY

Design of airborne digital systems is still in its infancy despite the rapid growth in technical capability, however it is possible to draw upon some U.K. experience in order to establish a small number of data points in the growth of development environments.

Warton Division experience in digitally based airborne systems can be charted over the past fifteen years, the three major programmes being the Jaguar, Tornado IDS and ADV aircraft.

Although initial work on the Jaguar started in the mid sixties it was 1968 before the choice of avionic system became clear. A certain amount of development work had already been done on some of the equipments but a considerable amount (8K) of main computer software development remained. The very basic tools consisted of a two pass assembler, link editor and loader with minimal test or monitor software in the accepted sense.

The early seventies saw the beginning of work on the Tornado IDS avionic system requirements. Despite some limited distributed computing this system consisted of a centralised computing architecture based on a single Litef Spirit III with eventually 64K words of memory. The assembly language associated with the computer was consciously chosen for the implementation rather than a higher order language on the basis of performance and availability. The major functions implemented include navigation, displays and weapon aiming.

System requirements were produced in the form of performance and design requirements (PDR) and subsequently subsystem specification. The former acted as the formal contractual basis for agreement between the particular companies responsible for the Tornado and, as (2) outlines, for convenience in terms of specification, functional commonality and operational specialisation, the avionic system was divided into a number of subsystems. For software these included:

- Navigation
- Displays and Controls
- Weapon Delivery
- Terrain Following/Automatic Flight Director

and for each a definitive specification was produced expressing the PDR in more detail both functionally and in terms of engineering and performance.

Software requirements were then produced reflecting the functional and operational requirments of the subsystem specification in more detail including relevant interfaces, software tasks and crew procedures together with logic and equation development.

Basic design or the establishment of the software architecture was within two frameworks

- a program structure hierarchy
- the features offered by the supervisor or executive software.

The program hierarchy consists of

- Operational flight program
- Subsystem, a functional/operational subdivision
- Package, basic relocatable program unit for program assembly
- Task, to allow selective iteration and iteration rate.

Further subdivision is possible at the package and task levels into routines and subroutines where the former is a conventional software subdivision and the latter is aimed at commonly used [illegible] level functions.

Programs were designed and coded in the Spirit III assembler language following a staged release philosophy and submitted to a number of levels of testing. With the exception of modelling to support the production and validation of software requirement documents the latter represents the first use of software tools encountered in the lifecycle and for brevity we will describe them as used at each stage of testing.

Stage 1 is the environment in which programmers generated, developed and tested their software and consists of two functions.

- 1A, the tools were based upon a host computer, the two main items being an assembler and an emulator. The assembler provided the creation of source and its conversion to object code, syntax checking, error reporting, listing (with cross referencing) editing and linkage. The emulator is a software model of the SPIRIT III Instruction set in which new software can be run and checked for storage and time requirements.
- 1B consists of a stand alone target computer on which the OFP can be statically and to some extent dynamically tested. External stimulation and monitoring is provided through a link to a PDP-11.

  Stages 2 and 4 embrace hardware/software integration, system integration and avionic rig acceptance with stages 3 and 5 providing airborne testing

It is clear that a development environment was only considered necessary from the coding stage onwards and that maximum effort was devoted to the testing phases.

An implementation representative of the mid seventies is to be found in (3) in the software for the Sea Harrier HUDWAC. Without describing it in some detail it differs in two respects from the one described above.

- the approach to partitioning
- the use of a higher order language

These differences are not unique to this implementation but illustrate a general trend in avionic software. Partitioning of the software requirements into functional tasks as a basic design step retains a relationship with a user view of the system. However, below this level each task may consist of a number of modules. A module is a single program containing one or more procedures, which is specified, written and initially tested in isolation from other modules. The function and input/output interface of each module can be specified together with guidelines for how it should be tested. The implementation led to programs being written in CORAL 66 with the attendant advantages of visibility and productivity. A hosted cross compiler was used producing binary code for a stand alone computer test facility with appropriate peripherals and monitoring software.

The above examples help to set the scene for the gradual expansion of awareness of the importance of earlier phases of the lifecycle, growing from the assembly language level outwards. This awareness has crystallized into the following trends:

- The repeated design of executives over several projects has led us to believe that there may be some virtue in adopting a rationalised executive with standard functions and features. If such an ideal were possible it would not only assist the design process but provide significant benefits in the form of portability, improved basic design and reduced support software costs.

- Build on the notional hierarchy of requirements already in use to provide a more formal structure and finer grain of detail which would support technical as well as procedural audits. This in turn would not only improve the quality of requirements (a very cost effective step) but also maintain a more detailed user view of the system being considered, assist traceability and enable conformance to be established between requirements and design.

- Widen the use of software tools to ascertain quality beyond the boundaries of code and test. Testing is a valid and important aspect in the production of software but it is expensive and the correction of errors is costly at this stage. More formal methods of production and in particular requirements should allow the use of software tools earlier in the lifecycle.

The range of tools employed on Jaguar and Tornado IDS are shown in Table (1) which is a slightly modified form of the comprehensive table to be found in (4). How these trends have been encountered in a more advanced design environment is discussed below but first let us briefly discuss the simple underlying model.

MODEL

The very simple model considered here consists of the phase orientated approach, each phase being supported by appropriate methods and tools. The particular phases chosen are shown in Fig (2) and embrace the production process from system requirements to maintenance. Whilst not wishing to discuss the relative merits of phase and process orientated approaches here it must be admitted that there is a significant amount of iteration not shown in the diagram. This iteration occurs not only between phases but also within them. These phases are:

- System Definition
- Software Requirement
- Basic Design
- Detailed Design
- Code
- Test
- Maintenance

Each phase produces an output by a transformation and/or enhancement of the input. This process should be supported by a methodology which provides order in the development and structure to the product. Put another way, this entails the steps to be followed during development and the notation to be used in expression. This in turn leads to more detailed models that relate to activites within each phase.

The remainder of this paper will consist of two uses of this model as it applies to the design of airborne computing systems. The first relates to the 80-85 time frame and is essentially aimed at producing software systems. The second is relevant to the second half of the decade and includes suggested extensions which would allow the specification of custom VLSI based systems.

CURRENT DESIGN ENVIRONMENT

The design environment described below is being applied to the embedded computing for an avionic system on a current project. It is considered to be representative of the capability expected to be generally available up to the middle of this decade.

A specific approach is described in terms of methods and tools but it must be stressed that there are probably viable alternatives available in particular areas of the environment.

Semi Automated Functional Requirements Analysis (SAFRA) is a phased lifecycle approach with a consistent set of methods and tools for each phase. A comprehensive description is to be found in Ref. (5).

The methodology used to develop and express requirements is Controlled Requirements Expression (CORE). This technique was developed jointly by BAe (Warton) and Systems Designers Limited and embraces a method for the assembly and analysis of information relevant to a requirement with an easily understood diagrammatic notation as the method of expression.

Two automated aids to production, validation and storage of the requirement and software design are a CORE graphics workstation and the University of Michigan's Problem Statement Language and Problem Statement Analyser (PSL/PSA).

The software design interface assumes the continuing use of CORE notation to produce detailed specifications with storage using PSL/PSA but aimed at the use of a rationalised executive and higher order languages. The former is the Modular Approach to Software Construction Operation and Test (MASCOT) and the latter are the UK MoD standard CORAL 66 and Pascal. A further assumption is the use of a commercially available MASCOT based software development and test environment for the testing phase working on the host-target principle, such as CONTEXT and PERSPECTIVE.

We will now consider the environment in a little more detail under the general headings of:

- Methodology
- Tools
- Lifecycle products

METHODOLOGY

(a) CONTROLLED REQUIREMENTS EXPRESSION

CORE is a method of analysing and expressing requirements in a controlled and precise manner. It enables a subject requirement to be expressed as either a number of lower level requirements or as a component part of some higher level. Any lower level requirement derived using CORE may in turn be subjected to the method to produce a hierarchy of lower levels. The lowest level is that at which the full method need no longer be applied and one may resort to strictly hierarchical decomposition making use of the notation alone. This is considered to occur after the basic design stage has taken place. In general the same notation is employed at all levels of requirement and design.

CORE diagrams utilise boxes to represent processes and arrows to represent data. The diagrams are time ordered from left to right and thus the box ordering specifies the sequence in which processes must occur. Symbol free boxes shown in parallel indicate indeterminate order and overlapping indicates a number of identical processes occurring in parallel. All input data entering a CORE diagram is referenced to a source and all output data to a destination.

The method comprises eleven logical steps which when applied to a subject requirement will decompose it into its lower level components but we will limit our description here to the following.

The method has three stages for each level of decomposition which may be summarised as -

- Information Gathering
- Propose Relationships
- Prove Relationships

Information is gathered with respect to a number of subdivisions of the problem, referred to as viewpoints, in terms of input and output data and gross functions. This information is refined by a Data Decomposition step which specifies in more detail the data already tabulated.

Relationships are proposed between the inputs and outputs for each viewpoint in turn and for data flowing across the viewpoint. The proof of such relationships is done in two ways; first the inter-relationship between viewpoints is examined and where such links exist then combined diagrams are drawn. Secondly, as these represent only particular paths through system operation another diagram is required which will illustrate such aspects as parallelism and the operational time ordering of processes. Examples of both diagrams are given in Figs (3) and (4).

The outcome of the above is a partitioned description (in terms of Viewpoints) with a detailed and hopefully complete picture of how the Viewpoints interrelate and react with each other as well as some indication as to the major functions contained within them.

It is now possible to extract the Subject Viewpoint as the one of interest and in turn take Viewpoints which describe how it is composed and repeat the methodology in full.

Such decompositions continue until functions emerge which may be seen to be implemented as software on a particular processor and at this stage it is possible to enter into basic design.

(b) MASCOT

MASCOT is a set of facilities for realtime programming containing features concerned with systems development and construction which include:

- A formalism for expressing the software structure of a system which can be independent of computer configuration and programming language.

- A disciplined approach to design, implementation and testing which supports the concept of modularity for real time systems and brings about added reliability by increased control over access to data.

- An interface to support the implementation and testing methodologies which is provided by a small kernel that can either be implemented directly on a bare machine (for operational use) or on top of a host operating system (during development) as well as software construction facilities.

- A strategy for documentation.

MASCOT views an application system as a number of activities, or processes, which operate independently and asynchronously but which co-operate by accessing shared Intercommunication Data Areas (IDAs). Thus the system can be seen as a network whose nodes are the activities and the IDAs whose directed links are pathways for data flowing between activities and IDAs.

Although the MASCOT facilities allow great variety in the implementation of IDAs, it has been found useful, for design purposes, to distinguish two conceptual classes of IDA according to the nature of the data flow which they support. These are called channels and pools. A channel supports undirectional data transmission, and has an input interface associated with a number of consumer activities. A pool provides a permanent data area in which data remains available for activities to read until it is specifically overwritten. The data in a pool does not have the essential transcience of channel data and reading it does not imply consumption, conceptually it has a simple bi-directional interface with associated activities.

MASCOT system designs are represented by Activity-Channel-Pool (ACP) diagrams and the logical outcome of a basic design phase using MASCOT would be a set of ACP diagrams showing the identified activities and how they are related through appropriate IDAs. Integrating a requirements phase using CORE with a basic design phase using MASCOT means transforming a requirement diagram into a design diagram as illustrated in Fig. (5).

(c) Software Design Scheme

This scheme covers the basic and detailed design phases of the lifecycle. The objective of the basic design stage is to convert the requirements expressed in CORE to a MASCOT Activity-Channel-Pool (ACP) diagram. The software requirement for a particular processor consists of a comprehensive data set comprising data flow and operational diagrams, data decompositions and some textual explanations.

Of this data set, the Isolated Operational Diagram is most nearly analogous to the MASCOT ACP diagram in that the operational relationships and the inter-communicating data flows are depicted between co-operating processes over the system lifecycle. The designers task is to take each process and assess if it is possible to implement it as an activity and to define inter-process data as formal Intercommunication Data Areas. Since the requirement data set will to a large extent provide the data decompositions it is a relatively easy matter to define the IDA data structures and test for feasibility of basic design bearing in mind the nature of data driven synchronisation primitives.

Detailed design for the activities involves what is in normal terms 'structured program design' but in CORE terms is called layer decomposition. Each process box which comprises the upper level activity is taken in turn, examined and a more detailed CORE diagram produced using the standard notation. If further statements can be made at this layer, decomposition is continued until a layer of detail corresponding to a simple design algorithm or assignment is reached and at this layer the activity is fully decomposed.

The coding stage or transformation into a higher order language now takes place with the assistance of PSL/PSA but this will be discussed below in the section on tools.

THE CORE WORKSTATION

The CORE workstation aims to provide maximum computer assistance in the application of the CORE method. It consists principally of a means of entering CORE diagrams at a graphics screen, storing them on disk and subsequently amending them, again from the screen. Hard copy of the diagrams is obtained using a printer plotter and some automatic checking is provided when the name of an item is entered on a diagram.

The interface with PSL/PSA consists of automatically converting a set of diagrams into PSL source and transferring this to the IBM mainframe for PSA report processing.

The basis of the workstation is a raster graphics generator and a 20" high resolution monitor with a keyboard and joystick. The resolution is 1536 by 1024 pixels and both a graphics and an alpha screen may be displayed simultaneously or independently. The software may reside on a PDP11 or the VAX series of machines.

A suite of graphics commands are available to allow construction and manipulation of diagrams including MOVE and MERGE. The first allows one or a number of interconnected objects to be repositioned within a diagram including the relocation of all the data lines involved. MERGE allows the contents of two diagrams to be merged and in doing so supports an aspect of the CORE methodology which calls for the examination of related data flow diagrams. It can also be used to construct and utilise templates of the most often used diagram formats.

The workstation embraces all types of CORE documentation including tabular information gathering, data decompositions, data flow and operational diagrams. A number of user reports are available which list relevant information concerning the diagrams on a particular database and both the process and data names used on them. An analyser checks name usage across all relevant diagrams including simple syntax and compliance with PSL rules. It also reports all other diagrams of a particular type that make use of an item both across a level of decomposition or down the diagram hierarchy.

The workstation is linked to PSL/PSA residing on an IMB 3083. PSL input files are generated automatically from the diagram data base and submitted via the link as an input to the PSL data base held on the mainframe. PSA reports return via the link for display at the workstation.

PSL/PSA

PSL (Problem Statement Language)/PSA (Problem Statement Analyser) is a product of the ISDOS project at the University of Michigan. PSL is a language which can be used for the description of a variety of system types from the highest level to the lowest while monitoring hierarchical and inter-relationships. It is English like and has some 18 object types which can be matched to the various features of the system to be described.

Conventions lay down the way in which CORE features are described using PSL. This entails the definition of object types such as PROCESSES, GROUPS, CONDITIONS, etc and the relationships between them. Although there are a number of CORE diagram types it is important that object types and their relationships are consistent across all documents since they will eventually all be stored on a single database intolerant of inconsistencies.

All PSL input files are produced automatically from a diagram database on the CORE workstation. PSA allows the establishment of a database, the running of reports on that database, its modification and control. Of these the most significant features are the 37 reports available to the definer which allow him to access information in a number of different forms. Obviously the richer the PSL description is of a given object the more can be made of PSA.

The broad category of reports are:

- Lists of names
- Matrix
- Structures
- Function flow

Reports can be run individually or combined to produce very powerful analysis. PSL/PSA is used to store and analyse CORE requirement datasets for consistency and completeness but its role in detailed design goes even further.

The layered activity diagrams are translated into PSL at each layer up to the point where decomposition terminates, i.e. assignment, decision table or basic construct, and it is possible to allocate the high level language and store it in the database. The detailed design phase, therefore, produces a database which contains the structure of the eventual program (in PSL) with the language elements embedded in it. The source file for a particular activity is produced by running a particular suite of linked PSA reports and a special formatter.

PERSPECTIVE

PERSPECTIVE is aimed specifically at the development of software for embedded computer systems written in Pascal. It is an enhancement of an earlier system CONTEXT, which produced programs written in CORAL 66, but both support the use of MASCOT as a design methodology and as such are interchangeable in the lifecycle approach described here. However, because it is more advanced we will restrict our description here to PERSPECTIVE.

The major components are shown in Fig (6) and its main features are as follows:

- To support the methodology used in software design and provide a safe execution environment for sequential programs in a concurrent system.

- A comprehensive configuration control scheme to prevent unauthorised access to software, ensure different project members interact in a controlled manner and to provide management information on the configuration of a software system.

- A facility to load application software into a target computer over a serial link which also allows debugging of the software remaining on the target from a host computer terminal.

- A standard run time package which can be tailored to meet specific requirements.

A description of all the components shown in Fig (6) is beyond the scope of this paper, the reader is referred to (6), but they are summarised below.

Configuration control is concerned with the management aspects of a project and implements a range of commands which actively support this function. For example, PERSPECTIVE has no MODIFY command, instead a CREATE command is used to create the next version of an item. PUBLISH is used to change the status of any item of software from "development" to "controlled". The former versions may only be manipulated by their owner but controlled versions may be used or read by other users which have access to them.

The Query facility allows inspection of the database including searching down cross-links, simple conditional expressions and an elementary mathematical capability.

The Constructor is responsible for deducing which items of software need to be compiled in order to construct the item required, extracting all the necessary interface definitions, symbol tables etc required.

Host checkout provides facilities for initial static as well as full dynamic testing. Static checkout identifies errors in the use of Pascal and can be applied to a single activity, dynamic testing must be performed using a test harness and can be used to investigate the dynamic behaviour of an activity or subsystem.

The down line loader allows the host to load programs into the target computer. Loading may either be done initially, in which case the entire system is loaded, or it may be invoked after a change, in which case only the code which has been affected by the change is reloaded.

The PROM formatter takes the output of the Constructor and is capable of slicing each contiguous block of memory both vertically and horizontally to blocks of formatted data for PROM programming equipment. The online checkout tool allows the user to connect the host computer on line to the target and then use PERSPECTIVE debugging facilities available for host checkout. Debugging commands entered at the host result in messages being sent up and down the line and the appropriate debugging actions taking place in the target.

LIFECYCLE PRODUCTS

At this stage it would be useful to review the lifecycle products of the methods used and the scope of the tools discussed above. Fig. (7) summarises these products for the lifecycle phases proposed in Fig. (2) and depicts the scope of the CORE Workstation with PSL/PSA and PERSPECTIVE or CONTEXT.

The number of levels of decomposition advocated for System Definition and Software Function are typical but need not necessarily be adhered to as they will vary with the size of the system and the degree of uncertainty about the original requirement.

From an operational point of view it is possible for the user to participate in all the phases of the lifecycle from a single workstation. The following observations may also be made:

- Users are working in a procedural yet understandable fashion which in no way acts as a barrier to the expression of originality or engineering skills.

- Each phase is supported by a computer based tool which not only improves productivity but also assesses quality.

- The products are held on a database for all phases making them amenable to a wider range of processing such as analysis and simulation.

CASCADE

In this section we will consider the class of design environment required for the latter half of this decade. This should be as comprehensive as possible in its treatment of implementation language and hardware with analysis and design aids for all aspects of avionic system computing. In order to discriminate between these objectives and those of SAFRA, it will be referred to as a Comprehensive Avionic System Computing Analysis and Design Environment, CASCADE.

Some of the design problems that will need to be addressed by CASCADE and more general observations are discussed below:

- The large processing requirements demanded by future applications which hope to capitalise on miniaturised general processing elements will contain a large degree of parallelism. The kind of system architectures that will efficiently achieve this for a wide range of applications is as yet unknown. The problem is twofold; how do you design with parallelism in mind and how do you effectively combine large numbers of general purpose computing elements to satisfy such a design?

- There will be areas of computing which due to their size or specialisation will require customised integrated circuits. Currently there is a gap between the methods and tools used to produce requirements and the CAD employed in the specification of specialised VLSI. A bridge needs to be built between the requirements and the system architecture abstractions.

- Viewed from this half of the decade the most important future software design stream appears to be that relating to Ada which despite some technical criticism could well become an international standard. While the spirit of the early STONEMAN document on the design environment embraced requirement specification the currently planned Minimal Ada Programming Support Environments (MAPSE) appear to only cover the phases related to software development (ie the phases covered by PERSPECTIVE above). Language independent design has been achieved in some measure within SAFRA but CASCADE would need enhancements to accommodate Ada's basic design concepts, specialised programming constructs and data typing.

- Despite the adoption of Ada we will have to support current languages beyond the end of the decade and hence CASCADE must include the ability to work with, for example, CORAL and Pascal.

- As more of the airborne decision making and control becomes vested in computing then the integrity requirements and quality of software will need to grow. Coupled with increasing complexity, testing becomes not only prohibitive in cost but technically impossible and hence the need for methods of verification and validation during the design process. Current analysis and verification techniques are aimed at the implementation language and could well be adopted to examine the products of earlier phases, particularly if the latter have discernible structure and are computer based.

The approach advocated with CASCADE is an evolution of the phased lifecycle via new phases in the design process and additional processing within phases which already exist. In particular:

- Enhancing the processing applied during the requirements phase.
- Multiple paths within the implementation phases to cover software and hardware design.

We will first consider some additional processing that could be brought to bear during the requirements phase.

The concept of program analysis to assist the quality assurance of software is readily accepted and particular techniques are starting to become established. For example, the method of using a directed graph to depict a sequential program and then analysing this representation to ascertain problem areas or quality of structure. The particular approach described in (7) has been used successfully in a high integrity application within the Division. It is currenlty being considered within SAFRA as a means of gauging the quality of mission software.

In CASCADE we would seek to apply the same technique to higher levels of design and requirements particularly as they are expressed in a form not far removed from the directed graph notation, as Fig (8) illustrates.

In practice an intermediate process would both produce the directed graph and perform the subsequent analysis by operating on a database containing the diagrammatic information. With time, this analysis would be replaced by formal verification.

A database of requirements produced using CORE and PSL contains much information of direct relevance to system simulation and modelling. This information is in the form of a definition of the system functions or processes with their corresponding input and output interfaces, together with timing details relating to the scheduling, interrupt priorities and performance requirements.

When combined with some model of the environment which could 'drive' the system this information can be used to simulate the system over a particular time period, providing the designer with data on queue lengths, throughput limits and other measures of overall performance. It is envisaged that CASCADE would employ a standard simulation package such as SIMSCRIPT or GPSS linked to the database to enable such simulation to take place.

In discussing the design aspects of CASCADE we will differentiate between the basic and detailed design phases.

BASIC DESIGN

In CASCADE the basic design phase consists of transforming a representation of the requirement into an architecture that reflects the medium of implementation. The starting point is taken to be the Isolated Operational diagram (IOD) mentioned above which was shown being transformed into the MASCOT ACP architecture.

The path to be followed for Ada is not very far removed.

The MASCOT activity and the IDAs include both control and data structures and being examples of the object orientated approach to program design they encapsulate a small set of software design decisions. The module termed an activity, is not an isolated subroutine or data structure but an interrelated set of procedures and data. The outside world is reached only through the IDA, including the data required and produced by the activity, while the latter's contents remain invisible to the user.

With Ada, the module becomes a package and has two parts, a specification and a body. The specification of the package acts as an interface describing the users access to the service provided by the package including all the information relevant to its use. The body of the package provides details of the algorithm and data structures that implement the function of the package.

An initial look at modelling MASCOT concepts within Ada was encouraging and we anticipate no major problems in charting the transition between CORE IODs and a software architecture consisting of Ada modules.

The basic design phase for hardware requires a different approach and depends upon the class of system being considered, we will first examine one requiring considerable parallelism to satisfy its performance.

Again, the problem is one of transormation from requirements to design using a method of representation which denotes the architecture of the final product.

Without stretching concepts too far one could conceive of a MASCOT machine in which General Purpose Computing Elements (GPCEs) host the activities and specialised hardware satisfies the neds of IDAs. The sequential process behind the activity would be implemented in the GPCE, in the normal way, with a library supported hardware specification system for the different kinds of IDA.

However, although MASCOT appears to satisfy the need for asynchronous processes with implied, although not necessary, concurrency, as a methodology it would require modifications in order to fully exploit parallelism. One which goes some way towards making this possible is the process oriented language Occam, developed by INMOS in the United Kingdom.

In Occam concurrency is conceivable down to the lowest levels enabling even isolated statements to function in parallel with each other. Groups of statements may be collected together to operate either in sequence or in parallel.

The order in which processes are executed is govered by three mechanisms:

- Sequential (SEQ)
- Parallel (PAR)
- Alternate (ALT)

along with conventional WHILE and IF constructs. Inter-process communication is governed by an unbuffered structure called a Channel (CHAN) which allows information to pass in one direction only and may also be viewed as a means of synchronisation. It behaves therefore as a read only element to a receiving process and a write only element to a transmitter.

Within CASCADE a possible link between the requirement and a multi processor system would be established by transforming the appropriate CORE diagram into Occam. This is shown for example in Fig (9).

DETAILED DESIGN

The systems considered above under basic design all lead to a conventional detailed design element of the lifecycle in that they eventually involve the production of software. The class of system yet to be considered is when we wish to produce a customised integrated circuit to solve a computing problem without recourse to a collection of GPCEs. In order to achieve it in CASCADE the relevant parts of the lifecycle need to be modified. Specifically we would introduce a duplicate path for hardware which would replace basic and detailed design, code and test with:

- Architectural Design
- Logic "
- Circuit "
- Layout "

Architectural design undertakes the partitioning and definition of relationships between major functions as identified in the requirement, from a designers viewpoint. Logic design decomposes these functions until the layer commensurate with logic elements is reached while circuit design transforms this into an electrical circuit with appropriate physical quantities. The layout phase seeks to optimise the circuit design in terms of path length and element proximity.

Each phase is served to a varying extent by the following:

- CAD tools
- Descriptive languages plus database and analysers
- Simulation
- Element libraries
- Method of decomposition
- Optimisation and product oriented processing

To describe all of these categories in detail is not only outside the scope of this paper but also precipitate from the point of view of CASCADE. However, to serve as representative examples a method of decomposition and a descriptive language have been selected as typical of those that would satisfy the needs of CASCADE.

A suitable methodology for decomposition is suggested by the REST Leaf Cell design system (8) and a layer decomposition undertaken similar to that used in the detailed design phase of SAFRA. The design is partitioned into small manageable pieces called cells which are similar to procedures in a programming language. A cell is considered to be rectangular in shape and all geometrical data is on the interior of the rectangle and considered to be the property of the cell. Each cell is composed of other cells or primitive elements which form a hierarchy of cells equivalent to the nesting of procedures.

The cells of a structured design are partitioned into two types, composition and leaf cells. A composition cell contains other composition or leaf cells while a leaf cell contains only wiring and primitive circuit elements.

The layered hierarchy which results from the decomposition of cells is similar to layering employed in the detailed design phase of SAFRA where instead of the terminating layer being a basic construct in the programming language it now occurs with the contents of a leaf cell. The description at this stage contains the most primitive functions (leaf cells), the hierarchical relationships (composition cells) and the geometric data associated with each cell. This database may then be used as the basis for subsequent phases involving circuit design.

Reference to a database implies a method of description that can be stored in this way and the use of what is generically referred to as a Hardware Description Language. Several examples of HDL abound but the one being considered within the context of CASCADE is ELLA, developed by RSRE (9).

ELLA was designed to cover a wide range of hardware design from below gate to above register transfer level. The language includes facilities for the description of networks and the behaviour of nodes and, because of its scope, nodes can be anything from transistors to microprocessors.

In ELLA the function declaration is a description of how a piece of hardware is constructed. It must be instantiated into a piece of hardware before inputs can be applied to it and outputs obtained from it and the constructs that realise function instantiation and interconnection are MAKE and JOIN. It is also possible to avoid duplicating instances of a function by calling a function and naming its outputs using a LET statement.

ELLA has no built in signals but instead functions may have inputs and outputs of any user defined TYPE and because the TYPES of all data are supplied, all JOINS may be checked by the ELLA compiler and inconsistencies detected. The language supports a top down approach starting from a structured high level description of the design, circuits being described, simulated and interactively debugged at subsequent levels.

If used in conjunction with the leaf cell concept then a low level cell representing an EXCLUSIVE OR function would be described in ELLA as shown in Fig (10).

It is felt that the largest effort in the construction of CASCADE will lie in the integration of tools which already exist, spanning the gap between requirements and design and improvement of user interfaces rather than significant original development of specific methods and tools.

Experience during the development of SAFRA has shown this to be possible for software but it has also demonstrated that a well structured expression of requirement can act as a useful spring board to other kinds of implementation and as such will act as an important step in the construction of CASCADE.

CONCLUSION

This paper has attempted to chart the progress of the airborne computing development environment in the medium and long term. The longer view, with CASCADE, is still a fairly notional one and is currently more of an expression of principle rather than specific methods and tools. However, it is felt that the most powerful link to be forged is that which lays between customer and designer or the bridge between requirements and design, whatever the medium of implementation.

Experience in the general computing fraternity is one of bringing the user closer to the solution of his problem by the use of high level tools and more usable methods of expression.

It is felt that a similar trend will be followed in airborne computing albeit over a much longer period of time due to the complexity of the problem at hand.

ACKNOWLEDGEMENTS

I wish to acknowledge the contribution of my colleagues via their work and in discussion and while the views expressed here are personal ones they could not have been formed without encouragement from the management of BAe, Warton Division.

I would also like to acknowledge the support of the Airborne Computing Systems Division of the Flight Systems Department, at RAE, Farnborough, U.K. in the development of the SAFRA approach.

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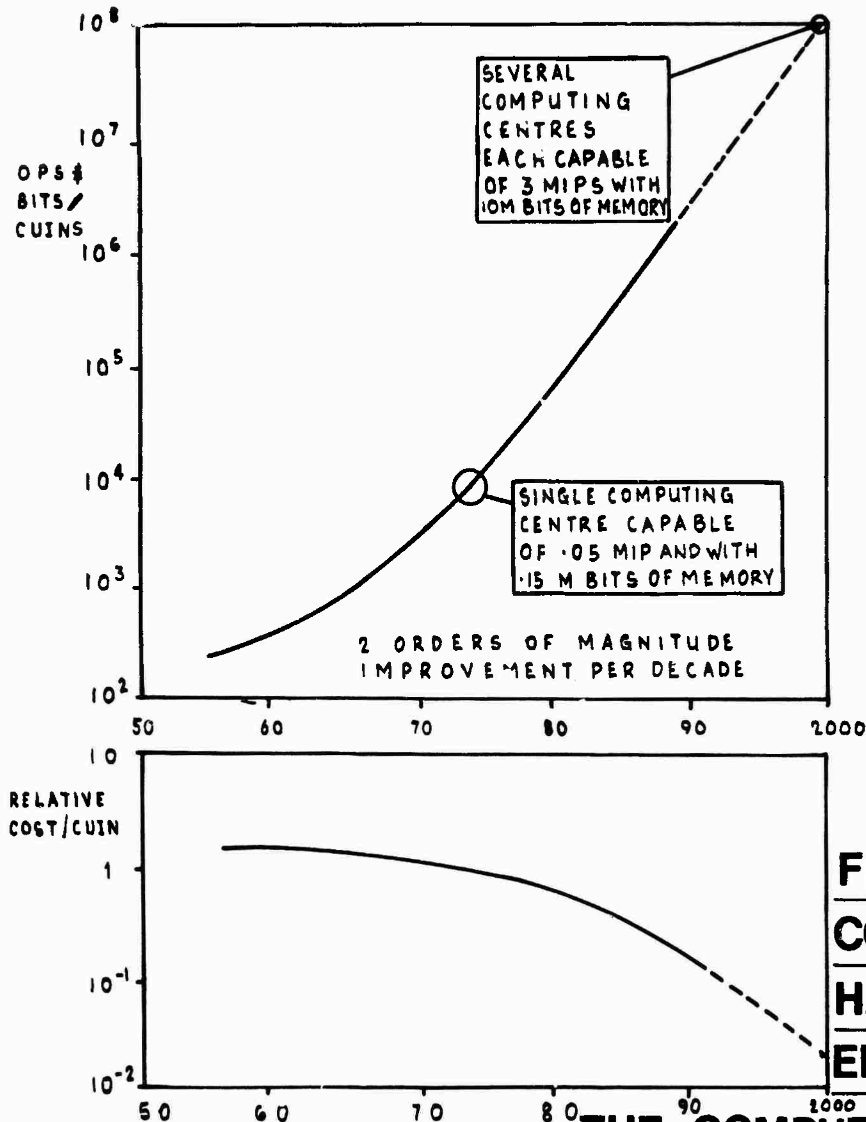
TOOL OR APPROACH	SEQUENTIAL LIFE CYCLE ACTIVITIES: RE-QUIRE-MENTS	DESIGN	IMPLE-MEN-TATION	SOFTWARE TEST & VALIDA-TION	SYSTEM INTE-GRATION & TEST	JAGUAR (70-75)	TORNADO IDS (75-80)	Current Project (80-85)
AUTOMATED TEST GENERATOR				X	X			
AUTOMATED VERIFICATION SYSTEM				X		●	●	●
ASSEMBLERS			X					
COMPARATORS		X		X				
COMPILERS & INTERPRETERS			X	X				●
COMPILER BUILDING SYSTEM			X					
COMPILER VALIDATION SYSTEM				X				
CONSISTENCY CHECKER				X				●
CORRECTNESS PROOFS				X	X			
CROSS REFERENCE PROGRAM		X	X					●
DATA BASE ANALYZER			X	X				●
DATA DESCRIPTION LANGUAGE		X	X					
DEASSEMBLER			X	X				
DEBUG AIDS				X			●	●
DECOMPILERS			X	X				
DYNAMIC TEST STATION				X	X		●	●
EDITORS	X	X	X			●	●	●
ENGINEERING SIMULATIONS	X	X					●	●
EMULATION		X	X				●	●
FLOWCHARTERS			X	X				
INSTRUCTION TRACERS				X				
INTERFACE CHECKER				X				●
LANGUAGE PREPROCESSOR		X	X					●
LIBRARY	X	X	X	X	X		●	●
LINKAGE EDITOR			X	.		●	●	●
LOADER			X	X		●	●	●
MAP PROGRAM			X	X			●	●
OVERLAY PROGRAM			X	X				
POSTPROCESSOR			X					
PROCESS CONSTRUCTION			X	X				●
PSEUDO PROGRAMMING LANGUAGE	X	X						●
REPORT GENERATOR								●
REQUIREMENTS LANGUAGE PROCESSOR	X			X	X			●
RESTRUCTURING PROGRAM			X					
SIMULATOR	X	X						
SOFTWARE MONITOR			X	X				
SOURCE CODE ANALYZER			X					
STANDARDS ENFORCER			X					●
STRUCTURED PROGRAMMING		X	X					●
SYSTEM SIMULATION	X	X						
TEST BEDS				X	X	●	●	●
TEST DRIVERS			X	X		●	●	●
TIMING ANALYZERS			X	X				
TRACE PROGRAMS			X			●	●	●
TRANSLATOR			X				●	●
UTILITIES			X					

TABLE (1) TYPICAL TOOL UTILISATION



FIG(1) TRENDS IN COMPUTER HARDWARE COST EFFECTIVENESS : THE COMPUTING CUBE

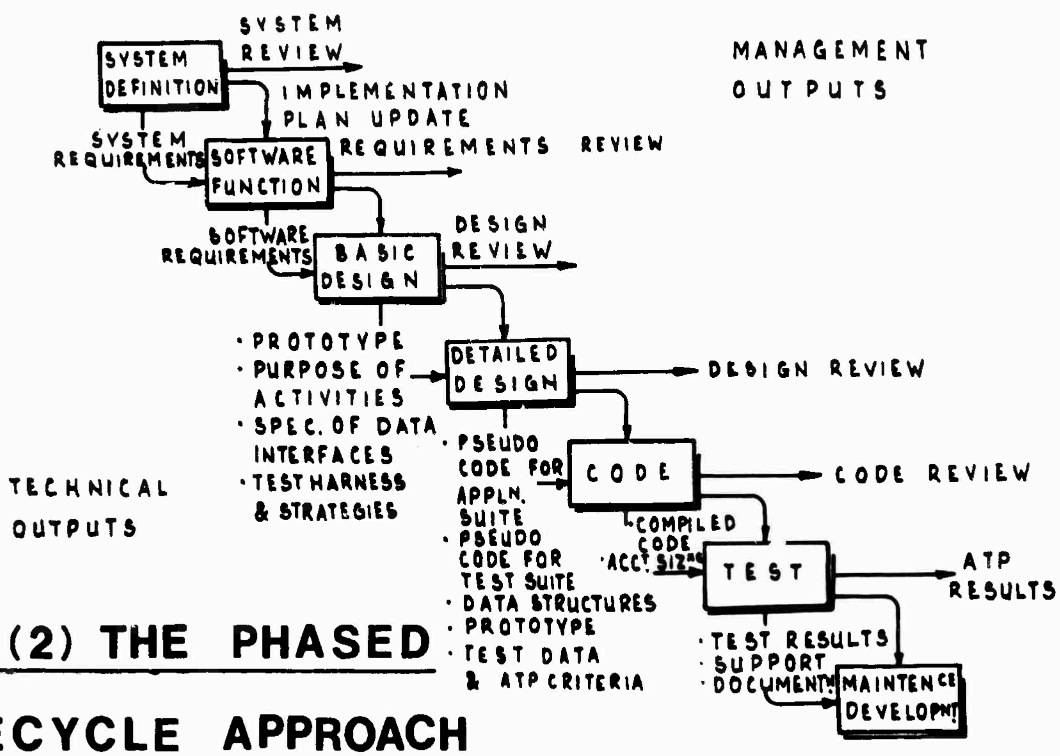


FIG (2) THE PHASED LIFECYCLE APPROACH

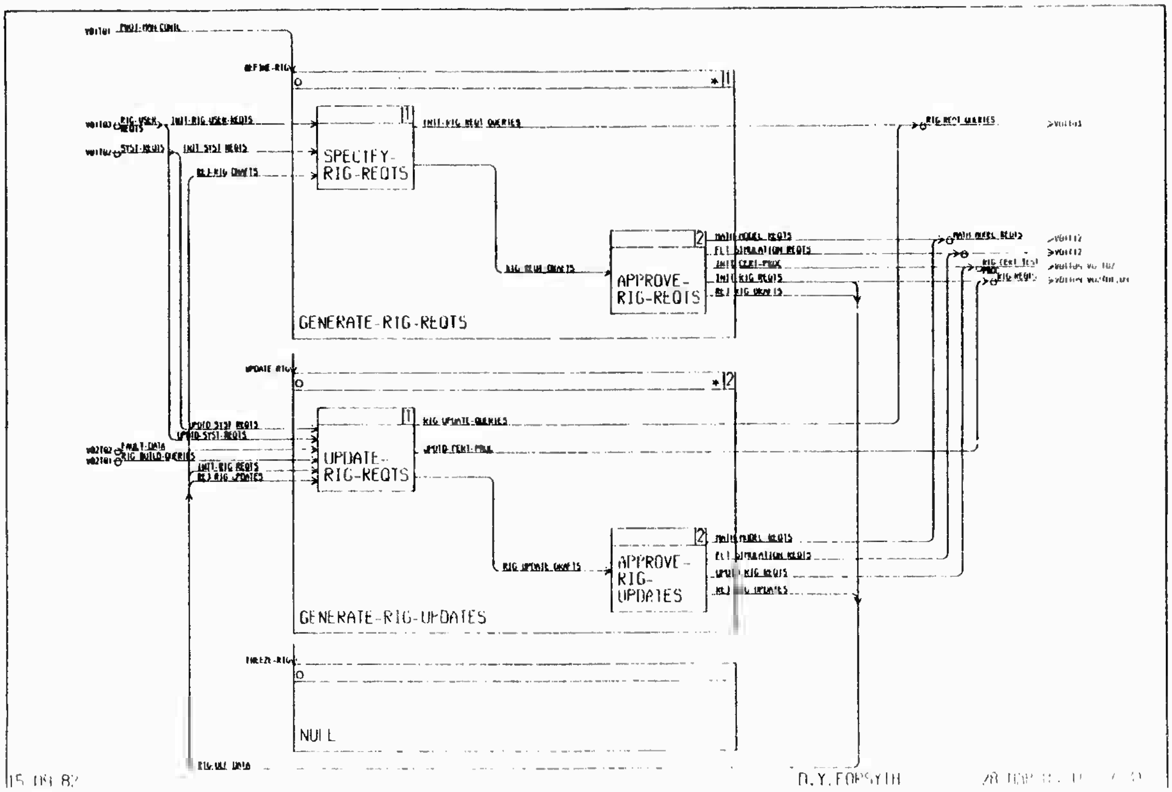


FIG (3) CORE DATA FLOW DIAGRAM

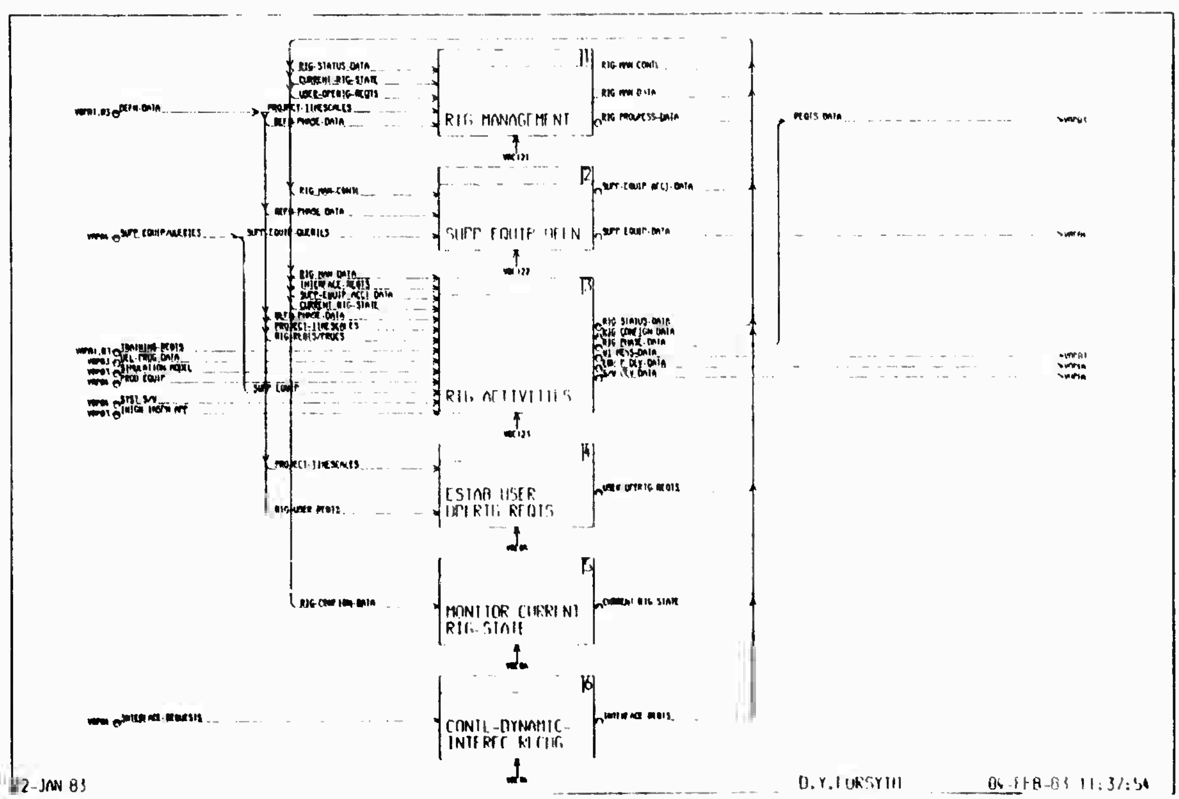
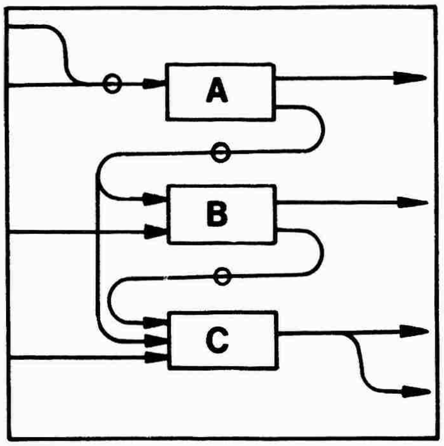
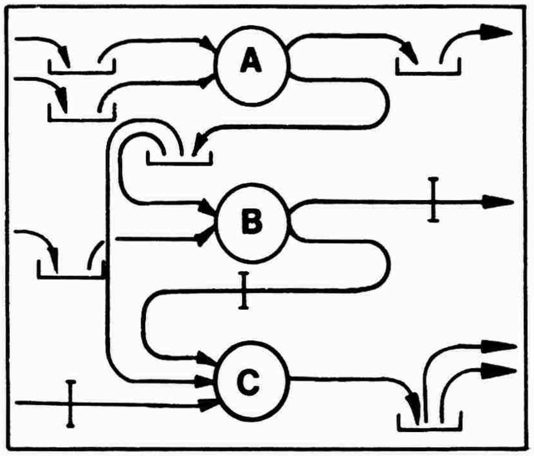


FIG (4) CORE OPERATIONAL DIAGRAM



ISOLATED OPERATIONAL DIAGRAM (REQUIREMENT)



ACTIVITY - CHANNEL-POOL DIAGRAM (BASIC DESIGN)

FIG (5)

TRANSFORMATION OF REQUIREMENT INTO BASIC DESIGN

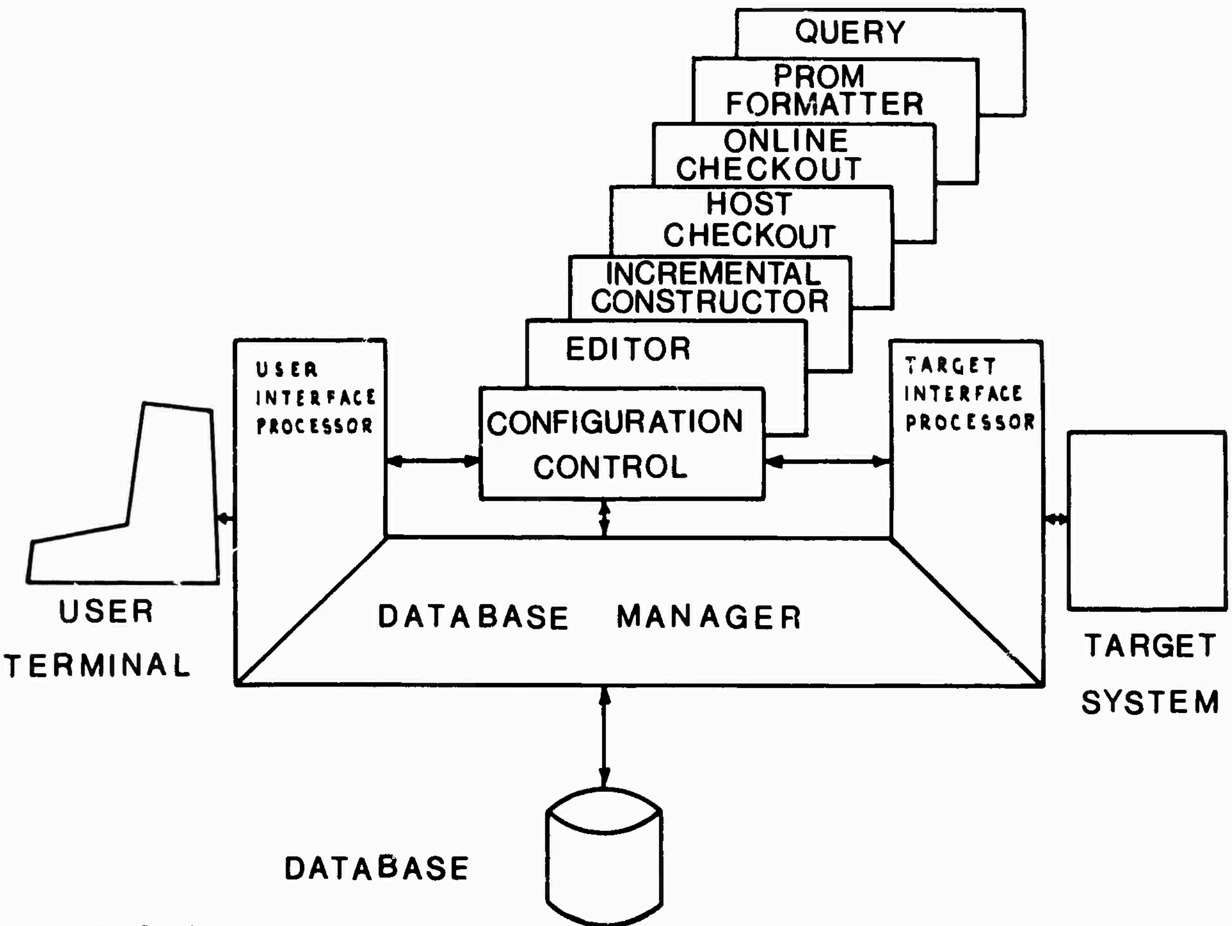


FIG (6)

THE MAJOR COMPONENTS OF PERSPECTIVE

FIG (7) SAFRA LIFECYCLE PRODUCTS

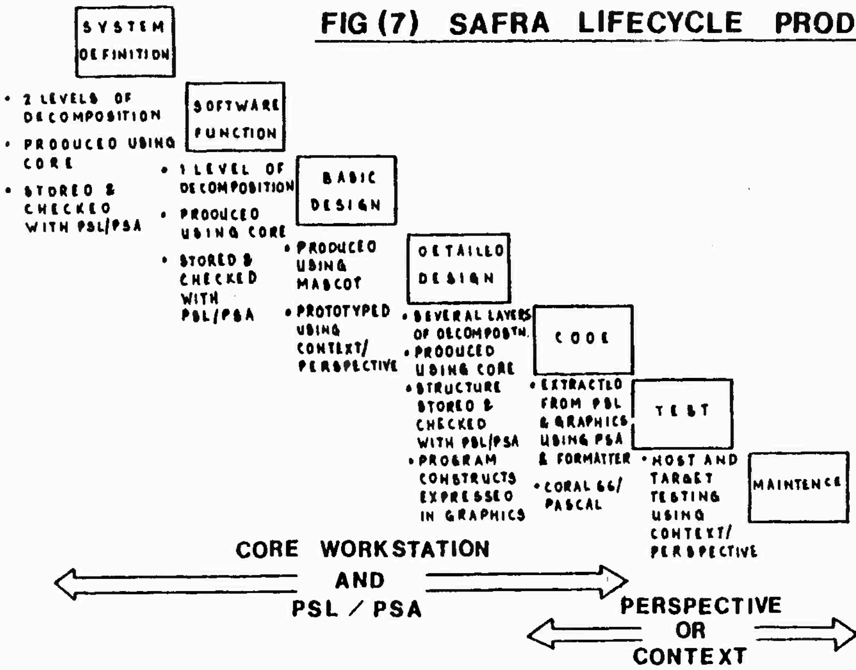
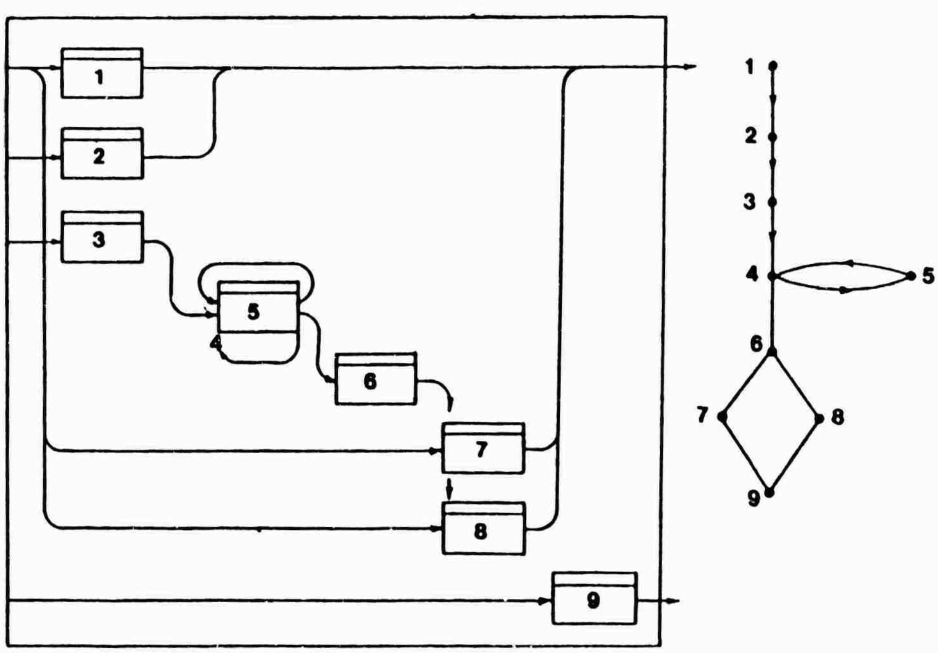
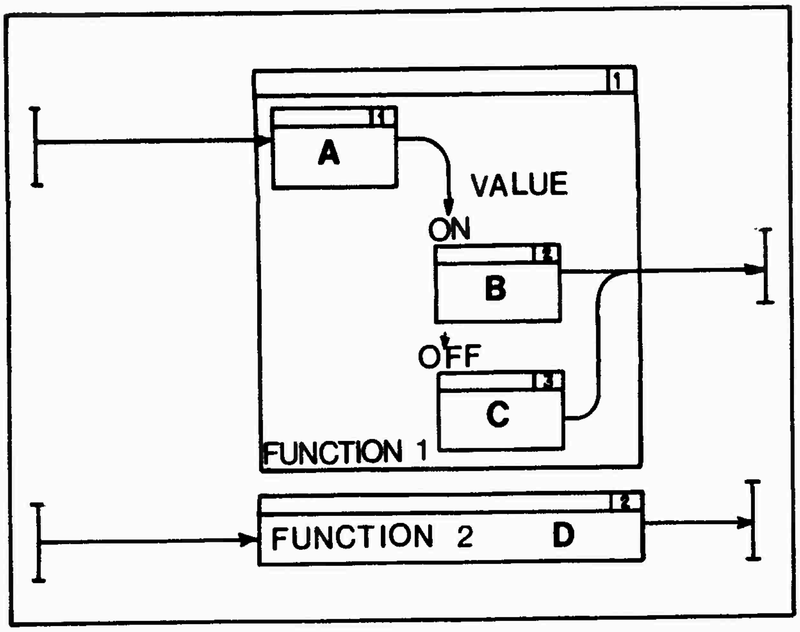


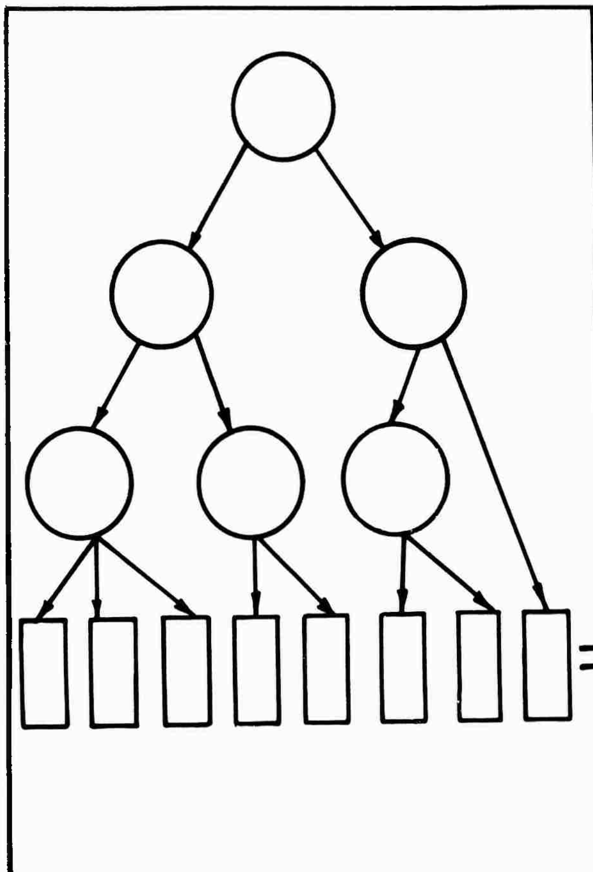
FIG (8) A CORE DIAGRAM EXPRESSED IN DIRECTED GRAPH FORM






```
PAR
    SEQ
        PROCESS  A
        IF
          VALUE
            PROCESS B
          NOT VALUE
            PROCESS C
     SEQ
        PROCESS  D
```

FIG (9) A SIMPLE CORE EXAMPLE DESCRIBED IN OCCAM



```
FN XOR:(bool ip1 ip2)→bool
BEGIN
   MAKE   AND: a1 a2,
          INV: i1  i2,
          OR : oi.
   JOIN   ip1→ i1,
          ip2→ i2,
          (i1, ip2)→ a1,
          (ip1, i2)→ a2,
          (a1, a2 )→ o1
  OUTPUT o1
  END
```

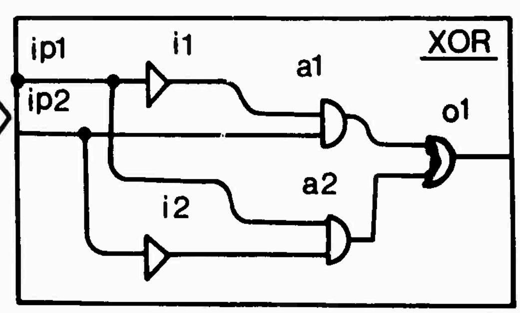


FIG 10 THE REST LEAF CELL APPROACH AND AN EXAMPLE OF ELLA

DISCUSSION

T.E.Spink, US

Your mention of the need for customized integrated circuits recognizes a real need, but unfortunately the likelihood of obtaining them for military purposes only appear slim since custom ICs must be produced in large quantities to be economically feasible. Current trends indicate that the custom IC must occur in large quantities within an avionics sensor or system to promote quantities which are economically feasible to produce. Ideally it is desirable that these special purpose ICs have a commercial application, but that is usually not likely since they are customized.

Author's Reply

While your observations on cost may have been true some little time ago I felt that they will not necessarily be so in the near future. The increasing use of Uncommitted Logic Arrays (ULA) for example, and relevant ULA design facilities have enabled the customer to become involved in the chip specification process. The growing availability of ULSI design tools and its appearance of "Silicon Foundries" mean that relatively small production runs of customised circuits are becoming economically feasible.

F.W.Broecker, Ge

(1) Do you have a set of evaluation criteria if you analyse the simulation of requirements in increased processing in your CASCADE-method?

(2) Do you agree that the kind (qualitative and quantitative and realism) of evaluation criteria has a vital impact on the result of analysis?

(3) Do we need a common set of evaluation guidelines and criteria for any kind of methodology for soft- and hardware system? (This includes CASCADE as well).

Author's Reply

(1) Clearly the exact nature of evaluation criteria will vary with the nature of the application being simulated but in a general sense performance must be of prime importance, whether this is the complexity of interpretation within a cockpit or the accuracy of weapon delivery.

(2) Yes I would, as in any venture the evaluation criteria are designed to succeed.

(3) Comparative studies for the benefit of the user community need and use such standard guidelines and they have been widely published in the United Kingdom.

A PRACTICAL APPROACH TO THE DESIGN OF A NEW AVIONIC SYSTEM

by

P.A.Duke
British Aerospace PLC.
Aircraft Group
Kingston/Brough Division
BROUGH
North Humberside, UK

British Aerospace is carrying out such a program with the

SUMMARY

This paper describes a programme to design, construct and demonstrate an advanced avionic system for the next generation of tactical combat aircraft. ~~The programme is~~ being carried out by British Aerospace at Brough with the prime objective of reducing ~~the~~ development risks associated with the rapid advance of technology. A number of factors contribute to this risk, notably the dramatic increase in system capability made possible by the general availability of LSI and VLSI circuitry. This has occurred at a time when the next aircraft project is likely to have a single seat cockpit.

Traditionally independant systems can now be linked using a data bus to provide a fully integrated system with the pilots needs foremost in mind. The system is based on a multi bus architecture recognising the differing integrity requirements of different parts of the system. A complete aircraft system is represented, divided into functional groups, and includes the basic aircraft systems such as hydraulics and fuel management and an integral maintenance reporting system. ~~The~~ mission systems include a wide range of sensor and weapon types, ~~and~~ the practical implications of introducing Mil.Std.1760 or the associated STANAG 3837AA standard store interfaces are being studied.

The avionic systems are linked to an Advanced Cockpit, with the objective of reducing pilot workload. The cockpit makes use of multi-purpose displays and an integrated approach to system control. A display of the out-of-cockpit scene is provided to allow the 'pilot' to operate the controls in a realistic manner and so provide representative input to the avionic system.

The development is based on an evolutionary approach through a series of readily identifiable intermediate stages. Configuration control, procurement and management techniques are being developed in parallel with the avionic system itself. This evolutionary approach will allow the maximum effectiveness to be derived from the recent technological advances.

1. INTRODUCTION

The production of a new military aircraft poses a challenge to the design team, which has to balance capability, cost and risk to produce a product which satisfies a customers operational requirements at a price he can afford. The pace of new technological developments continues to grow, offering the possibility of increasing system capabilities to levels only dreamt of a few years ago. However, because of these rapid changes it is very easy to fall into the trap of assuming that a particular component or technique is readily available or fully understood. A customer needs to know the level of risk he is accepting at the begining of a new aircraft project, as problems encountered late in development can be very costly to rectify.

Since the last major aircraft development programme in the UK, significant advances have been made in the miniaturisation of electronic components. Large scale and very large scale integrated circuits (LSI and VLSI) are available which allow computational power to be applied locally, wherever it is needed, and this trend is continuing into the VHSIC programme. Traditional system boundaries are being broken down and the architecture of an avionic system is no longer clear. Many alternative ways of allocating system functions to Line Replaceable Units (LRUs) and interconnecting these units are possible, and this confusion has been aided by the development of digital serial time division multiplexed data transmission, ie. the data bus. The amount of information which can be transferred between LRUs is no longer limited by the weight of inter-system wiring.

Whilst system capability, in terms of the number of functions available, continues to grow, the pilot still only has two hands, with a total of ten fingers, two eyes and two feet. We can try to increase the number of control channels open to the pilot by providing direct voice input, head pointing systems and synthetic voice output devices. It is clear however that we can only go so far in this direction and new methods of achieving control over the total system are needed, to reduce pilot workload generally and to achieve Hands On Throttle And Stick (HOTAS) control during combat.

In an attempt to answer some of the more important questions raised by the new technology and thereby reduce risk, the UK Ministry of Defence (MoD) has established an Avionic Systems Demonstrator Rig (ASDR) at British Aerospace Brough. The project was first described to this group at a conference on tactical airborne distributed data networks, held on 24th June 1981, and subsequently to the 13th annual conference of ICAS held at Seattle during August 1982. The Rig is now well established having overcome a number of major technical hurdles, and has become a tool which can be used to support the development of new aerospace equipment. The objective of this paper is to examine the Rig as a concept and then to briefly describe the progress we have made.

2. THE REQUIREMENT

Advanced avionic systems for the next generation of tactical combat aircraft have been studied by the UK MoD, with the support of British industry for a number of years, and whilst many conclusions have been drawn. It was recognised that significant experience could be gained with the new technology in a ground based rig, in order to provide a lead into the next aircraft project. Such a programme could reduce the risk factor and allow a more advanced system to be implemented in the future aircraft than would otherwise be possible.

The need for such a rig programme was accepted by the UK MoD in the late 1970's, with the present project commencing early in 1980 following extensive discussion within British industry. A number of overall objectives were defined and agreed with the MoD to form the ground rules on which the Rig was built. These are far reaching, covering both technical and managerial aspects. As listed below the overall objectives are:

- to support the development of avionic systems for a future tactical combat aircraft
- to provide practical experience with an advanced avionic system using data bus communication
- to demonstrate the techniques of software management
- to support the development of new maintenance procedures
- to investigate the specification, procurement and management procedures required to develop future avionic systems
- to develop new system control strategies and to demonstrate the acceptability of these to the pilot
- to provide a national facility to support the development of future projects

3. THE METHOD

The ASDR provides a substitute for a real aircraft project, and whilst the future aircraft configuration remains unclear, the architecture of an avionic system suitable for such an aircraft can be defined. The specification, procurement and integration of that system then form the basis of the project.

Any new avionic system will rely on the data bus to provide the main method of communication between components of that system. Hence the development of a data bus based on the UK Defence Standard 00-18 (Part 2) must be the starting point. The first stage of the project is therefore to construct and operate a dual redundant data bus and to use this to transfer data in a representative manner between elements of a simple avionic system. This requires the specification and construction of a bus controller and remote terminals, and from the outset it was decided to implement all transmission modes including broadcast and acyclic transactions. Once the bus is available then simple system simulations can be produced to generate representative data. The problem of system control is also introduced at this early stage, and in order to produce realistic control inputs it was decided that a 'pilot' should be included in the control loop.

It was considered unlikely that a future avionic system would use only a single data bus. The dissimilar redundancy and integrity requirements of various parts of the system and the natural functional partitioning of the system lead to a multi-bus architecture. Stage 2 of the rig development therefore includes expansion of the avionic system to include additional buses. This requires the development of inter-bus communication techniques and the production of a bus controller which is also a remote terminal on a second bus.

The expansion in the complexity of the system and the quantity of dynamic data produced at Stage 2 requires the development of bus monitoring and analysis techniques, beyond the capability of commercially available equipment. Also possible at this stage is the development of a maintenance philosophy and monitoring equipment. The cost of maintaining existing aircraft is very high and an improvement in this area was recognised to offer potentially large savings in the cost of ownership of the next aircraft. The equipment used to provide maintenance data should ideally simply monitor data on the buses and not require any special features to be introduced into the avionic equipments.

Stage 3 includes expansion to represent a full avionic system and therefore involves the specification and procurement of many items of equipment from avionic suppliers. To embark upon this phase without experience of the procurement procedures represents a large risk for the Rig project. A number of the equipments for Stage 2 are therefore procured from industry to establish these procedures, and to allow time to amend procedures found to be deficient before committing large quantities of project funding.

Stages 1 and 2 establish the technological base and managerial procedures necessary to produce an advanced avionic system using data buses. However the system implemented at the end of Stage 2 is relatively simple and cannot be considered to fully test the new techniques.

Stage 3 closely resembles the production of a 'real' aircraft system, involving system definition, specification, procurement, integration and operational demonstration. The design of the Stage 3 avionic system was bounded by adopting the following guidelines:

- the system should be representative of that required for a tactical combat aircraft

- the system is intended to support a wide variety of projects and therefore requires flexibility wherever possible

- the system requires to be separate, both philosophically and practically from the 'outside world' stimulation

It is necessary to make assumptions about the nature of the operational requirements for the aircraft whose systems are represented on the Rig and to establish performance levels which affect the avionic requirements. In particular the aircraft missions must be defined and hence the approximate aircraft size and capability. In addition it is necessary to define the weapon loads required to fulfil those missions.

The system is specified at the functional level with a functional requirement specification being produced for each system element, describing what that element is required to do, but not how it will be implemented. These specifications serve two purposes: to provide the raw material from which the total system architecture can be derived, and to provide the basis from which the system procurement can proceed. In order to procure equipments then the functional elements must be allocated to hardware units, bearing in mind the practical constraints imposed by aircraft installation factors. Constraints are also imposed by the ground rig, such as development timescales, the desire wherever possible for flexibility, implementation limitations to constrain costs, and limitations imposed by the 'outside world' stimulation facility.

Equipment procurement specifications are then produced, each comprising two parts. Part 1 is common to all specifications and includes conditions which are applicable to all equipments eg. available power supplies, and the preferred programming language. Part 2 contains detailed requirements for the particular equipment and should be written sufficiently broadly to allow each vendor flexibility to offer proposals that they consider to be advantageous to the project. At the same time it should be sufficiently precise to guarantee that the equipment provided will fully meet the defined requirements.

Following the submission of proposals the choice of vendor is based upon:

- compliance with the Equipment Procurement Specification

- cost

- delivery timescales

- design advantages and disadvantages

In addition to the specification and procurement activity there are the large central tasks of providing the 'outside world' stimulation, defining the overall system control mechanism and data flows and integrating the systems together.

It has been stated that one of the prime objectives of the Rig is to demonstrate system acceptability to the pilot. Hence in addition to a major emphasis in the cockpit design on the ergonomics of the pilot's task it is important to consider pilot workload, and to achieve the correct balance between direct pilot interaction and automatic system actions.

Many of the objectives of the rig programme will be achieved during its development, in terms of procedures, techniques and equipment generated. The end point of the current project is considered to be the successful demonstration of the operation of the defined system over a number of defined mission phases.

4. THE IMPLEMENTATION

4.1 The Rig Facility

To house the Rig and the Advanced Cockpit a new building was constructed at Brough, providing laboratory, office accommodation, computer facility and a demonstration area based on the cockpit and outside world display system. The overall Rig facility is shown in Figure 1.

4.2 Developing the Data Bus

The first task was to produce a data bus, and this was achieved by first developing sufficient hardware to construct a simplex bus and then expanding this to a dual redundant standard by adding extra interface hardware. The equipment was based on a commercially available microcomputer, the Plessey MIPROC 16AS, which has a processing speed sufficient to allow the necessary DEF. STAN. 00-18(Part 2) response times to be met. Hardware interface cards were developed by British Aerospace and software produced to cause the microcomputer to function as either a remote terminal or bus controller. A Fairchild data bus monitor/controller completed the initial system. The Rig at this stage was used to transfer artificial data from one location to another to demonstrate all bus transfer mechanisms.

4.3 Stage 1

Stage 1 capability was achieved by developing software for the MIPROCs to simulate system functions. A dual navigation function and a fuel system function were selected in order to generate a wide variety of data types and rates and to allow investigation of the handover between duplicated functions. Software for the MIPROCs is developed on a Digital Equipment Corporation (DEC) VAX 11/780 computer and downloaded into each microcomputer at the start of a run. The VAX 11/780 also provides the outside world stimulation of the systems, in the form of aerodynamic and engine data, outside world display data and a Rig command and monitor function.

The Stage 1 Rig shown in Figure 2 is completed by providing pilot control and display interfaces. Advantage was taken of an advanced cockpit development programme already underway at Brough to provide these facilities. The Rig and Advanced Cockpit activities are complementary and allow the Rig to receive realistic control inputs whilst the Advanced Cockpit activity has a representative avionic system to control. The combined Rig/Advanced Cockpit facility also provides an excellent demonstration capability.

In order to provide the interfaces between the cockpit and the Rig a number of special units were produced. These were the Controls Management Processor which formats switch data for transmission over the data bus and receives data from the bus to drive discrete warning indicators in the cockpit, and a waveform generator pre-processor. The Ferranti waveform generator was made available with the cockpit and the pre-processor constructed to provide the remote terminal to the bus and some display data processing. The final unit shown in Figure 1 is a map drive interface unit which is needed to drive the moving map function of the Ferranti COMED head level display.

4.4 Executive Control

The major achievement of Stage 1 has been the development of an embryo Executive function which provides much of the automatic system control, and is resident in the same microcomputer as the Bus Controller. Its position in the control hierarchy is shown in Figure 3. Executive control is that control of the total system which manages the combined operation of the various sub-systems to achieve the required overall state. Executive control uses pilot selections and sub-system status data feedback, in the form of Status Words and State Response Words, to generate the control commands to the systems. These commands are transmitted over the bus in the form of State Control Words which are used to provoke changes in the overall system state. The changes required can be as a result of pilot interaction or as a consequence of, for example, a sub-system failure. One particularly useful capability of such a system is the ability to reconfigure the total avionic system automatically according to the mission phases.

It is tempting to use the Executive function to control all system changes. However, such a centralised system would require an unnecessarily large control program. Following detailed study it was decided to allow sub-systems autonomous control of those internal functions which do not directly effect other sub-systems.

4.5 Enhancement of bus techniques

At Stage 2 a second data bus is introduced (Figure 4) to allow investigation of the operation of two asynchronous data buses. This second bus is referred to as the General Services bus as it provides communication between those services such as fuel management, hydraulic management, environmental control and electrical power generation which are basic to the operation of the aircraft. The general services bus controller is required to have a remote terminal onto the first bus, now referred to as the avionic bus, to allow inter-bus communication.

4.6 System Procurement

As has already been mentioned, Stage 2 is intended to test procurement procedures, and so the bus controllers for the avionics and general services buses were specified and procured from industry. The problem of redundant executive and bus controller operation is investigated by specifying two bus controllers for the avionics bus. The dual navigation system was also procured from industry to investigate the specification of data interfaces and system operation, and to allow system testing and integration procedures to be established.

4.7 The Outside World bus

Another important feature of the Stage 2 Rig is the clear distinction between the avionic system and the "Outside World" stimulation. The Outside World has been provided with its own bus and bus controller to allow communication between the general purpose computer and those functions requiring stimulation. It is considered too difficult and expensive to provide real aircraft sensors such as the Inertial Navigation platform and then attempt to stimulate them. Instead, emulations of the sensing functions are provided such that the interface with the rest of the system appears to be realistic, but with the sensor data being supplied over the Outside World bus.

4.8 Redundant displays and data analysis

Other features of the Stage 2 Rig are redundant waveform generation for the pilot's displays and the addition of a data recording and analysis system. Redundant display generation was provided by procuring a second waveform generator and pre-processor and constructing a video multiplexing unit. The ability to monitor, record and analyse data bus traffic has been provided by developing an interface to the Fairchild Data Bus Monitor/Controller to down load bus data into a mini computer and then onto hard disc storage. An analysis program operates on the stored data subsequent to completion of the rig run.

4.9 Functional Decomposition

Stage 3 of the rig development expands the system functions to include all those which would be required for a tactical combat aircraft. To help define what those system functions should be, B.Ae. obtained the support of a group of senior design engineers from a number of the largest UK avionic suppliers. This group performed a "Top Down" functional decomposition of the complete avionic system, within the overall ground rules mentioned earlier, and produced a set of functional requirement specifications. This approach resulted in the overall system being divided into four major groups of sub-system functions.

. the Aircraft group

. the Pilot group

. the Navaids group

. the Mission group

The Aircraft group comprises those avionic sub-systems which are concerned with keeping the aircraft flying safely. This group is mainly safety critical and contains the flight and engine control systems and the general aircraft services which include fuel management, hydraulic management, the control of aircraft power, environmental control and the associated sensors and actuators. The general services systems are arranged so that the management functions are distributed and associated with at least two processing units. Each processor would be expected to carry out one of the main management functions, secondary data control and local data collection. It is intended that each sub-system should be capable of independant but reduced operation in the event of a complete failure of the General Services bus. This group also includes a maintenance data recording system which stores both trend and fault diagnostic data from the various sub-systems. The data is stored for subsequent retrieval and will provide rapid and direct interpretation of a failure by ground personnel. More detailed maintenance data is available for off-line analysis.

The Pilot Group embraces what are normally considered to be the cockpit controls and displays facilities, and in this particular architecture also contains the executive control function. The displays system assumes a full CRT suite of four displays, including the Head Up Display, and a completely independant reversionary display system implemented in an alternative technology. Clearly there is a limit to the quantity of information which can be absorbed by the pilot at any particular phase of a mission and the intention is to provide him with only that information which is relevant for his immediate task. Hence the mission has been broken down into phases such as Take-off, cruise etc. and the displays organised by the avionics executive function to provide the appropriate information. The controls sub-system is based on a multi-purpose control panel which interacts closely with the avionics executive, and dedicated switches which are divided into two side consoles. The starboard side of the cockpit is used for once-a-flight switches. The main attack and defensive systems can be operated without the pilot having to take his hands off the flight control stick and the throttle, however a number of dedicated system selection switches are still required and these are located on the port side of the cockpit.

The Navaids Group of system functions provide the basic ability of all aircraft to navigate and communicate effectively. The group consists of inertial sensors and processing, radio navigation aids, communications system and a briefing aid. In addition to providing basic position, attitude and velocity data, the navigation system calculates the required heading, track, ground speed and time-to-go to make good a desired destination or route. The radio navaids include the TACAN and MLS systems. The briefing aid allows the pre-flight insertion of data into systems concerned primarily with navigation and weapons control. Extensive use is expected to be made of this function to reduce the amount of manual data entry.

The Mission Group of systems include the basic aircraft sensors such as the radar and electro-optic systems, the Stores Management System (SMS) and the essential defensive aids. The SMS provides safety critical outputs and a data bus interface to advanced weapon types via the standard store interface defined in Mil.Std. 1760 and the associated STANAG 3837AA. Communication between units of the SMS is again achieved with a data bus. Attack packages will be set up from data briefed into the system at aircraft start-up, but allowing the pilot to manually override the initial settings. The weapon aiming function is distributed, with the air-to-ground processing being carried out within the navigation system and the air-to-air processing within the Radar.

4.10 The Avionic System Architecture

The system elements identified as a result of the functional decomposition were brought together by B.Ae. to form the architecture of the avionic system to be produced during the Stage 3 expansion. This is shown in figure 5. The resulting system is in many respects more comprehensive than would be included in a single seat aircraft, but provides the facilities for further development work.

4.11 Timescales

The initial contract for the Rig was placed in mid 1980 and it is intended that Stage 3 will be complete in mid 1984.

5. PROGRESS AND PROBLEMS

Stage 1 of the rig development was completed in the autumn of 1981, with relatively few major difficulties. Some delays were incurred through the unreliability of commercial equipment and the use of compilers which were found to be incompletely tested. The main task of proving data bus communication was achieved with only minor changes being required during the integration phase.

Stage 2 has proved to be a more difficult task with delays being introduced during sub-system development. The bus interfaces were no longer under the direct control of B.Ae. and hence required to be specified in considerable detail to sub-contractors. Minor deficiencies or ambiguities in the specification can result in incompatibilities which do not become apparent until the sub-systems are integrated. The process of integration has also proved difficult as a faulty word from one sub-system can have unexpected results in other parts of the overall system. The data acquisition and analysis facility has been found to be a very important diagnostic aid. New system testing procedures have had to be developed and a specialised testing facility was found to be required.

As expected, all major difficulties have occurred in the area of the data bus interfaces and lessons have been learnt which are now being applied to Stage 3. Specification, development and testing procedures are established and the design of the bus controller and executive function have been verified. To aid the production of executive software various software tools have been produced. These include an automatic program generator to produce the finite state control logic. This reduces coding errors and has a user orientated input stage. A further program allows a user to specify state control words and state response words by English language input. It is difficult to overstate the importance of the executive function which in many ways is the heart of the new avionic system. Without it the avionic architecture shown in figure 5 would be difficult to achieve and the control of the overall system by a single pilot would be difficult if not impossible. The control functions performed by the executive have allowed the number of control switches to be reduced and have made the concept of the advanced cockpit a viable proposition.

Stage 2 is now essentially complete and a large amount of experience has been obtained. Stage 2 has achieved its prime objective of generating confidence in the Stage 3 expansion programme.

Stage 3 equipment specification and procurement has been underway for some time with some systems being at an advanced stage of development. Major lessons have still to be learnt but these are now associated with the management of data interfaces rather than data bus techniques.

6. STATE OF THE ART

In a short period of time the ASDR has allowed significant advances to be made at a relatively low cost. The data bus is no longer an unknown quantity and, whilst care is required to use the technique, its advantages can now be realised. UK industry is generally aware of the new design approach and has a number of new product lines. The UK MoD. is gaining the confidence it needs before committing large amounts of money to a new aircraft project and has a design tool which can be used to support that project.

During the course of the Rig programme many new possibilities for system operation have emerged which have had to be excluded for cost or timescales reasons. The Rig forms an ideal environment in which to develop these new ideas and many lines of future development are envisaged.

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8. ACKNOWLEDGEMENTS

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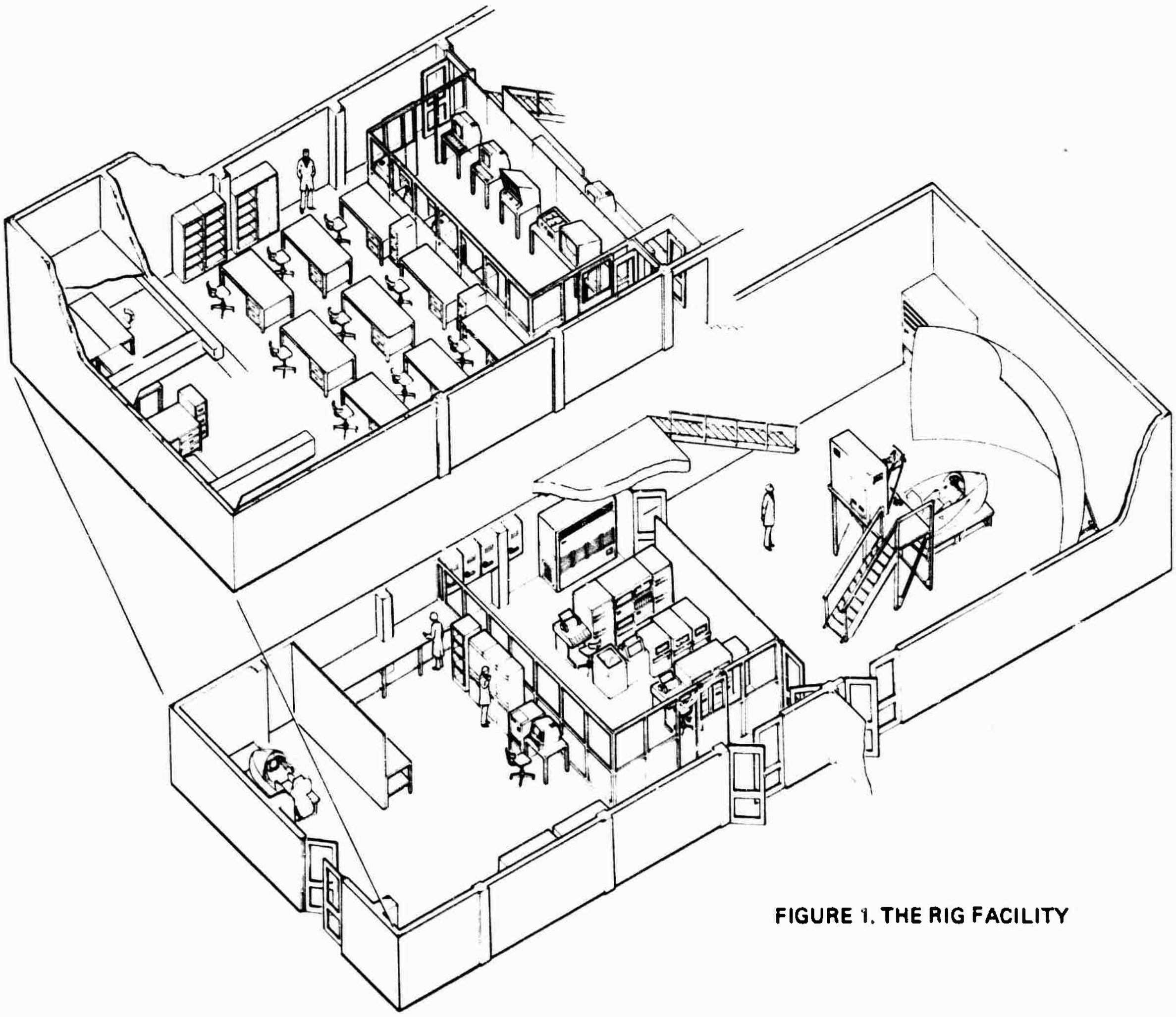

FIGURE 1. THE RIG FACILITY

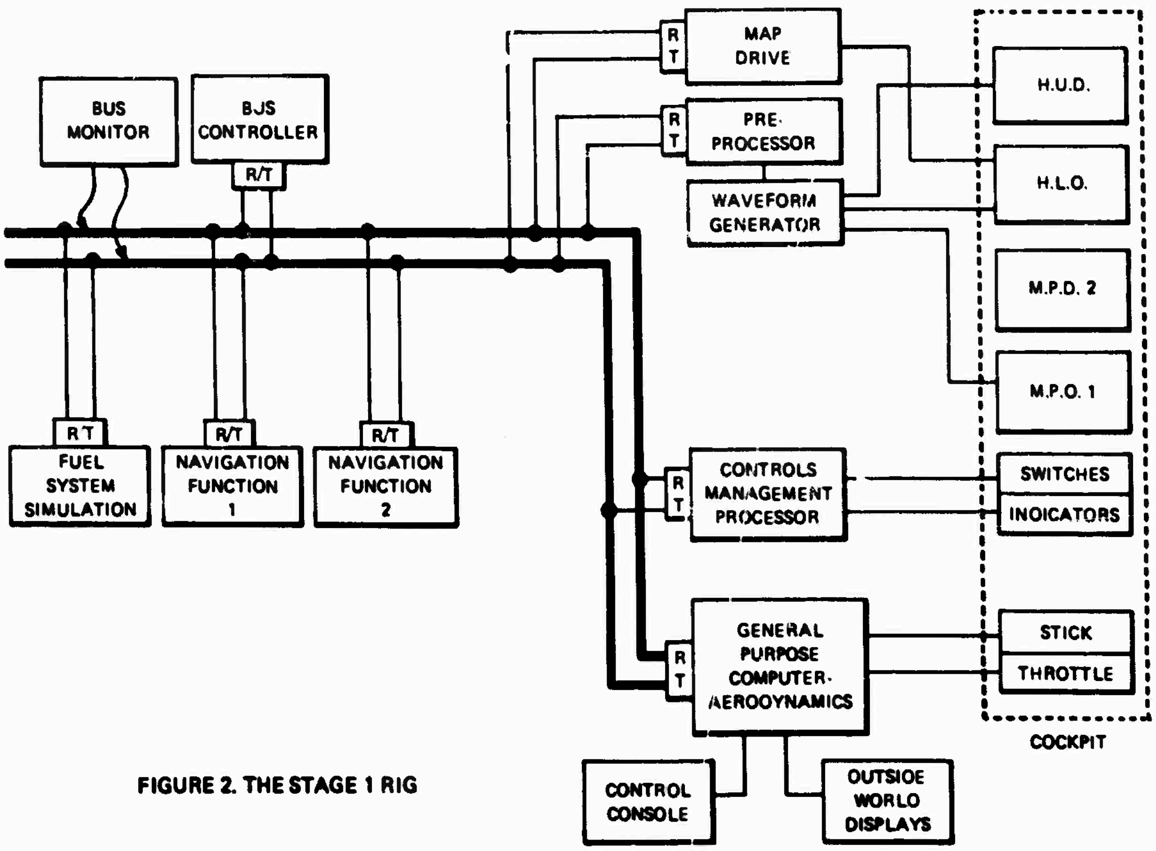

FIGURE 2. THE STAGE 1 RIG

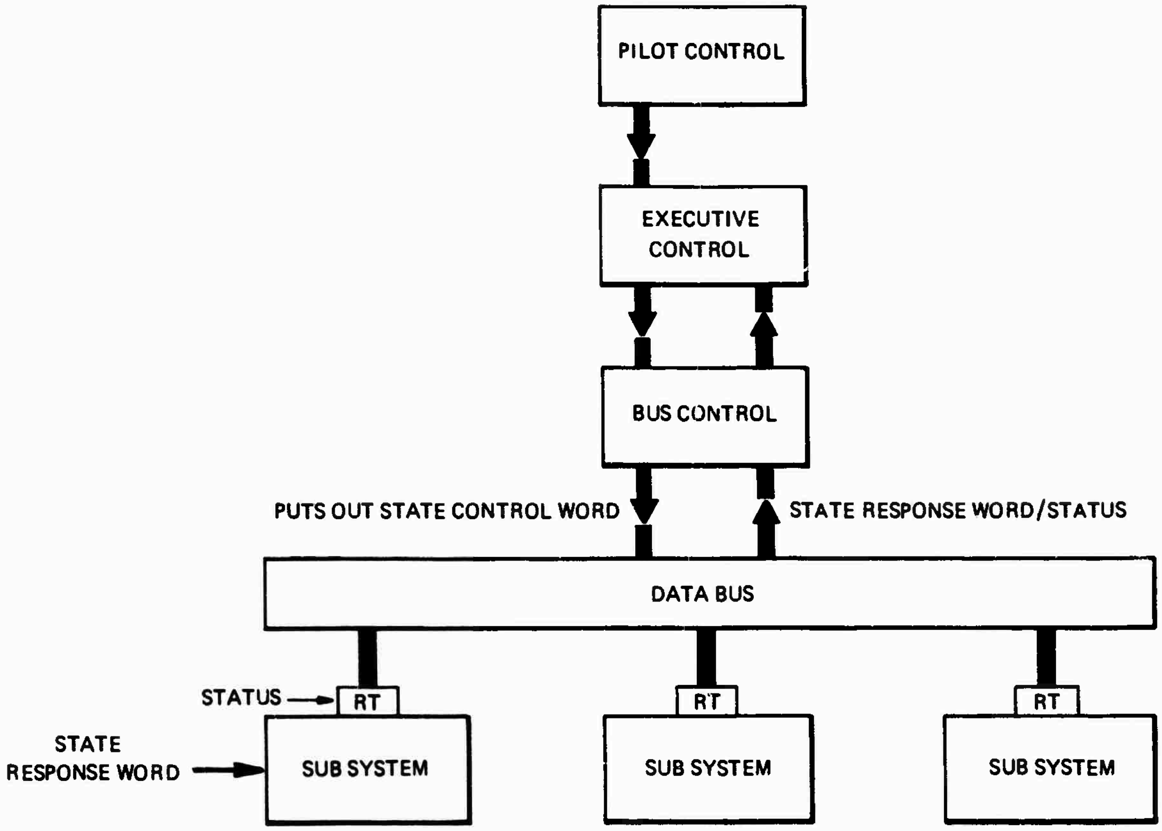

FIGURE 3. SYSTEM CONTROL

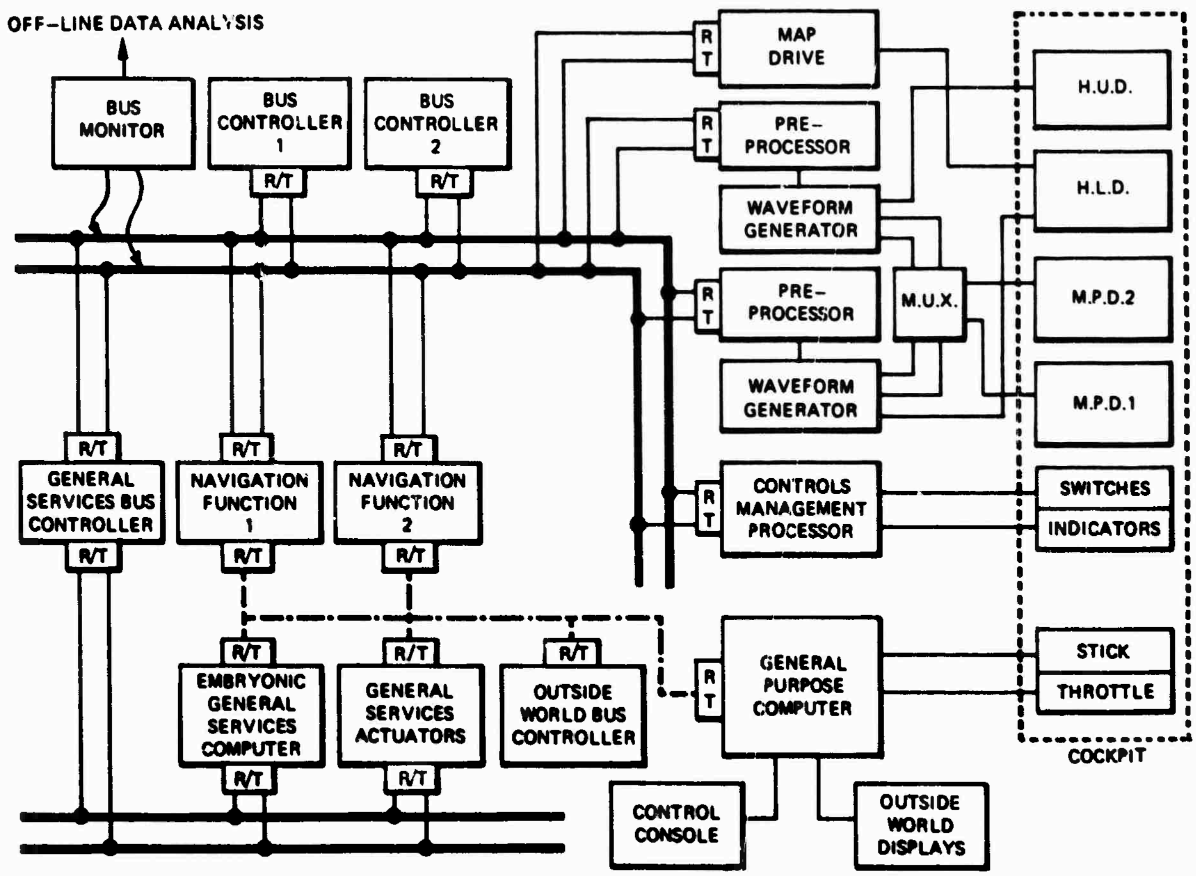

FIGURE 4. THE STAGE 2 RIG

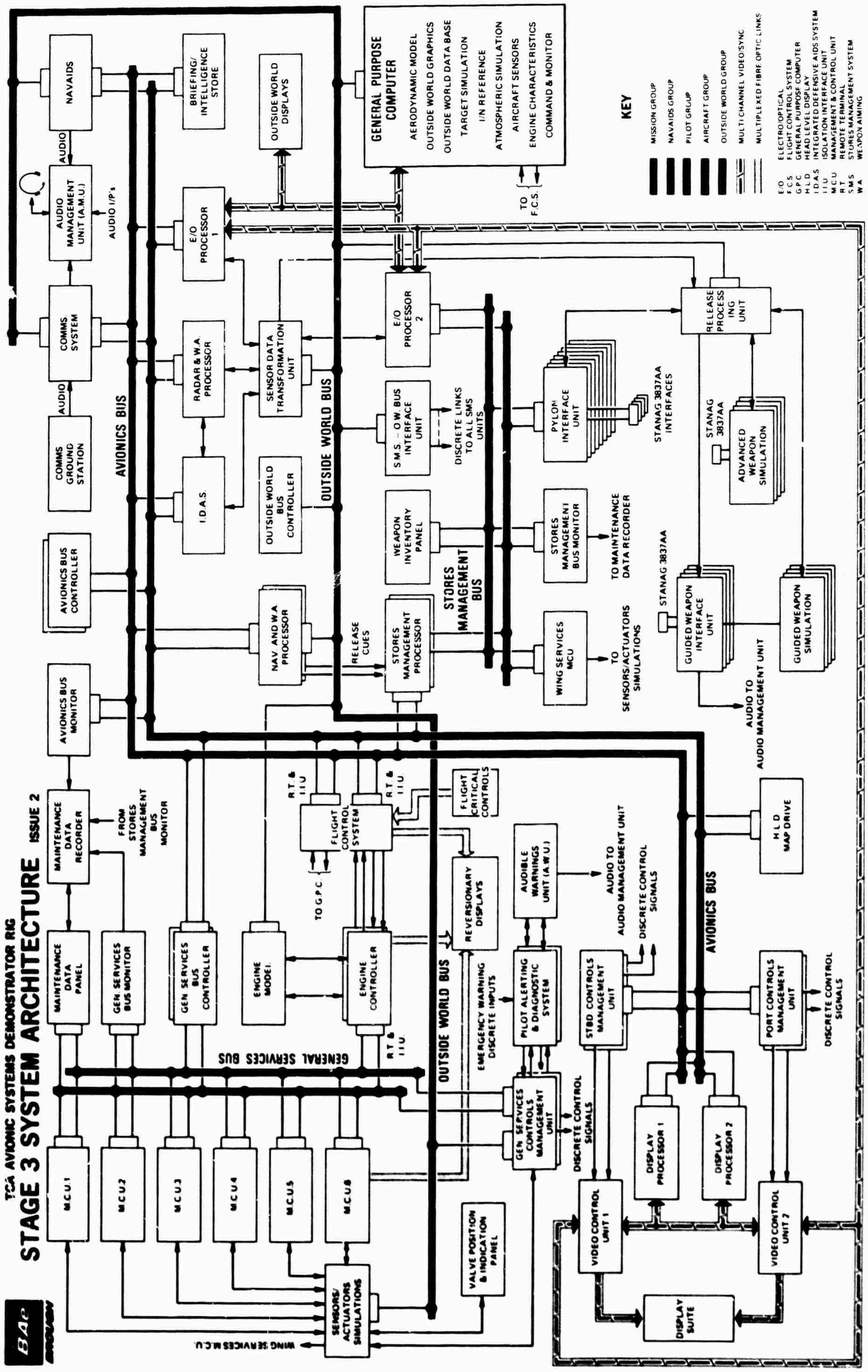

FIGURE 5. THE AVIONIC SYSTEM ARCHITECTURE

DISCUSSION

J.F.Irwin, US

What criteria and arguments were used to determine what system elements or functions are assigned to a specific bus and how do you communicate global information (i.e. broadcast)?

Author's Reply

The major consideration for the partitioning of buses was the differing integrity requirements of certain system groups. For example the general services or utilities functions are flight safety critical and so they are kept segregated. This does not mean, however, that the loss of the general services bus hazards the aircraft since the total system is designed to survive this situation. The armament bus uses an unusual protocol to reduce latency of time critical messages and so the SMS functions are kept segregated to avoid causing problems to other systems not tolerant of this protocol. Global data and certain other multiuser high rate data is transferred by using the 1553 broadcast technique. The interbus protocols described in the paper are able to support interbus broadcast.

M.Burford, UK

Has the demonstrator rig the capability to insert data in order to either generate errors or to continue the simulated mission in a formal, self documenting dynamically closed loop manner?

Author's Reply

Yes. It is possible to dynamically inject faults into any part of the system in real time during a flight. We also are able to record the operation of the system before, during and after the injection of faults or the occurrence of real defects. This data can be analysed after the flight using an interactive computer-based system. Manual analysis would be almost impossible due to the enormous amount of data produced during a run.

G.Hunt, UK

Has your use of the 1553B data bus in the Brough Rig work shown up any deficiencies or limitations in the bus standards?

Author's Reply

Yes. Some indication would be useful of whether Transmit-Receive and Broadcast subaddress should be overlayed or segregated, possibly by defining CLASS I or CLASS II terminals for overlayed or segregated options. The content of at least some of the bits in the R/T fault word should have been defined and not left to the R/T implementor. Contiguity is not specified in an unambiguous way but has to be inferred from other parameters. It needs to be specified for both transmitters and receivers in such a way that the transmission characteristics of the bus cable are allowed for.

INTEGRATION OF ICNIA INTO ADVANCED HIGH PERFORMANCE FIGHTER AIRCRAFT

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INTRODUCTION

An aircraft Communications Navigation snd Identification (CNI) system traditionally consists of a number of independently operating "radios" each providing a unique communications, navigation aid or identification function. Each radio was probably developed autonomously with little regard for any of the other CNI functions. The technology used in the circuitry of any function depends upon the time frame in which the black box was designed. Thus, the circuitry in the equipments in CNI systems may run the gambit from vacuum tube equipment to LSI. Furthermore, the technology of the function itself, i.e., modulation techniques carrier frequencies, etc. is of the time period in which the function was developed. Consequently in the most recent CNI equipments, some rather outdated techniques are performed by some rather sophisticated circuitry.

The modernization of military CNI is deterred by two factors. First, the CNI system, unlike a radar or a display, must operate with an outside cooperating station. Second, CNI systems not only perform the command and control function for the military mission of the aircraft but also are required for the regulation of flight in civilian controlled airspace. Both of these factors mean that the modernization of a function, say for instance a change in modulation technique for a communications system, must be accomplished throughout all aircraft and all ground stations, in a given time period. Unless such a change results in a large benefit, the economics of the change is prohibitive.

In the 1950s, CNI equipments were integrated from their "bits-and-pieces" status into a single system. An example of this is the AN/ASQ-19 CNI system developed for the F-4 airplane. However, these systems consisted of the repackaging of existing radios into several boxes physically tailored to fit the airplane and using a common power supply. This approach eased the equipment installation problem but did little else for treating CNI as a system.

In the 1960s, the military began a series of studies on a Unified CNI (UCNI) system. This concept changed all the military communications, navigation aids and identification functions so that they would use a common waveform in a common frequency band. The technology for this approach is sound but the problems of transition from conventional CNI to UCNI are practically insurmountable. Furthermore, unless the transition included civil aircraft control facilities, military aircraft would still be required to carry some conventional CNI when operating in civilian controlled airspace.

The alternative to unifying the CNI waveform and frequency is to unify the CNI equipment itself and retain the present waveforms and frequencies. Through several studies, this approach has evolved into the Integrated CNI avionics (ICNIA) presently under development by AFWAL today. This paper examines the incorporation of such a system into modern high performance fighter aircraft.

WHAT IS ICNIA?

Any CNI function can be reduced, in a rather simplified manner, to three elements:

- A receiver-transmitter
- A signal processor
- A data processor

A block diagram of such a function is shown in Figure 1. In the receive mode, the RF waveform is received and converted to baseband in the receiver-transmitter. The baseband signal then flows to the signal processor where it is converted from its transmission format to a common digital format. The common digital format is presented to the data processor for storage and for distribution to the aircraft avionics system. In the transmit mode, the data to be transmitted is gathered from the aircraft avionics system and processed into a digital format by the data processor. This signal is passed to the signal processor which converts it to the required transmission format at baseband and sends it to the receiver-transmitter. Here the baseband signal is converted to the transmission frequency, amplified and transmitted.

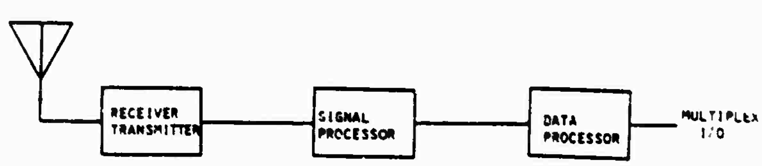

FIGURE 1. GENERALIZED CNI FUNCTION

With today's technology in processors, it is possible for a single signal processor and data processor to handle all CNI functions. Therefore, by interfacing several receiver-transmitters with the signal processor an integrated CNI system can be realized. Except for the High Frequency Communications (HF Comm) function, the CNI functions operate either in the VHF, UHF or L Band portion of the frequency spectrum. If the receiver-transmitters are made up of switchable building block components which are switched under the supervision of the data processor, the ICNIA system can become adaptive. The data processor selects the CNI functions to be activated at any point in the mission. If one of the receiver-transmitter building blocks fails in flight, the ICNIA can reconfigure itself by switching receiver-transmitter components so that only the lowest priority CNI function is lost. If priorities change during the mission, the data processor will reconfigure the receiver-transmitter components to reflect this change.

This is the concept being developed by ICNIA. An overall block diagram is presented in Figure 2. The CNI functions being incorporated into ICNIA include:

- o HF Voice Communications
- o VHF Voice Communications with Antijam capability
- o UHF Voice Communications with Antijam capability
- o IFF transponder
- o IFF interrogator
- o TACAN
- o ILS/VOR
- o JTIDS
- o GPS
- o AFSATCOM

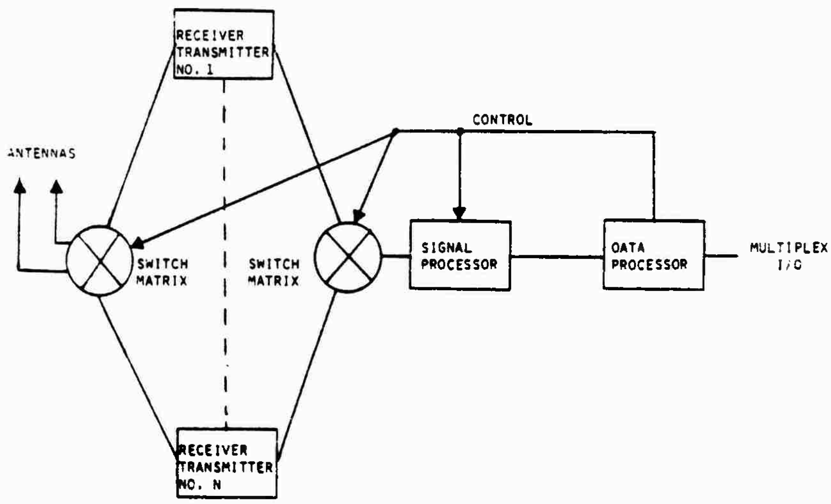

FIGURE 2. SIMPLIFIED ICNIA SYSTEM

ICNIA offers the avionics integrator three advantages over present CNI equipments:

- o A unified system which is readily compatible with the architecture of modern aircraft avionics suites.
- o A highly reliable CNI system due to its ability to reconfigure itself and thereby "repair" high priority functions.
- o A considerable savings in CNI space, weight, power and cooling requirements.

Furthermore, it attains these advantages without impacting the established CNI waveforms.

ICNIA INTEGRATION INTO AIRCRAFT

The historically autonomous nature of CNI equipments results in a number of possibilities for integration of an ICNIA system into an airplane avionics suite. These possibilities range from incorporating many ports on the ICNIA corresponding to the ports on the individual equipments to bringing the total ICNIA I/O across a multiplex port - perhaps even a fiber optic port. The selection of an interface technique must be consistent with the avionics suite of the host aircraft.

Obviously, the most desirable interface with ICNIA would be via multiplex bus only. However, in older non-multiplex bus aircraft the implementation of such a technique may be cost prohibitive, and in some cases the nature of the I/O signals may not allow them to be readily multiplexed. Communications signals are normally audio for voice or some form of digital data for data links (e.g. JTIDS). The Navigation Aids signals are usually synchro and meter movement signals which drive aircraft instruments. IFF I/O signals are limited to control signals, in the case of transponders, or a video signal which is mixed with radar video, in the case of interrogators. Some of these signals can easily be handled in a digital multiplex format, while others will present problems in certain installations.

To illustrete ICNIA interface with eircraft two types of evionics suites will be considered. The first is en aircraft without an avionics multiplex interfece. This will represent the older aircraft in service todey. The second will show an aircraft evionics suite with a dual multiplex bus interfece such es is being designed today.

Actually, the integretion of ICNIA into non-multiplex avionic suites is the more difficult of the two cases stated ebove. The impact on this clese of aircreft is higher beceuse very few standards existed for interfaces between subsystems when these eircreft were designed. Therefore, the ICNIA interface would require teiloring for each type of aircreft. However, it is conceiveble that by the time ICNIA becomes operetional, the older eircreft will have been updeted to a multiplex architecture. Indeed, it would be pleusible that ICNIA would be retrofitted es part of en evionics update program. This situation would allow the complete redesign of the evionics suite to a multiplex architecture and allow the retrofit cost of ICNIA to be shared with other emerging systems.

ICNIA is designed to eccomplish the majority of its I/O via a multiplex bus. The exception to this rule is that the audio I/O will be analog. Unfortunately, the non-multiplex bus airplene cannot use the CNI signal outputs on the multiplex bus. Consequently an ICNIA Adaptor is necessary to interface the multiplex bus I/O of the ICNIA to the hardwired CNI displey and control interface. This interface is shown in block diagram form in Figure 3. The ICNIA Adeptor will interface with the multiplex bus on the ICNIA.

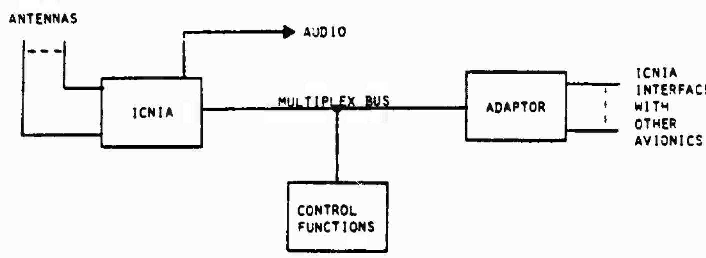

FIGURE 3. ICNIA INTEGRATED INTO NON-MULTIPLEX AIRCRAFT

The functions of the Adaptor are as follows:

- The passthrough of navigation dete between the GPS function and the Avionics System.
- The pessthrough of navigetion deta between the JTIDS function end the Avionics System.
- The collection of eircraft stete vector data for JTIDS transmissions.
- The formatting of JTIDS displey dete.
- The digitel-to-analog conversion of Nevigetion Aid dete (TACAN, ILS, VOR) for displey on the analog instruments (HSI, ADI).
- The ecceptance end passthrough of initializetion deta for JTIDS end GPS.
- The ecceptance end passthrough of stetus monitoring and reporting dete for ICNIA.
- If required, eccept control signals of various formats from the ICNIA function control boxes and pass them to ICNIA via the ICNIA multiplex bus.

The control functions mentioned in the last point will be discussed in a separate section of this paper.

The integretion of ICNIA into e multiplex interfeced evionics suite is considerebly simpler. Consider en avionics suite architecture shown in Figure 4. This is e two multiplex bus system. One bus, the evionics bus, or A bus handles primarily navigation data while the display bus, or D bus handles displey dete. While the system contains many new avionics subsystems, those of interest to ICNIA ere en Up Front Control (UFC), a Data Transfer Unit (DTU), a Programmable Displey Generetor (PDG) and two Multi Function Displays (MFD). The Central Computer has two independent multiplex ports and is the bus controller for both buses. The UFC is e control which provides pilot interface with the Central Computer end control of the CNI equipment. The DTU is e unit which accepts e date storege device (such es PROMS) end, from this device, provides mission data (e.g. waypoints) end initialization data to the various subsystems (e.g. JTIDS). Note that data can be passed through the central computer to the equipments interfaced with the displey bus. The PDG end MFDs form a versatile display system.

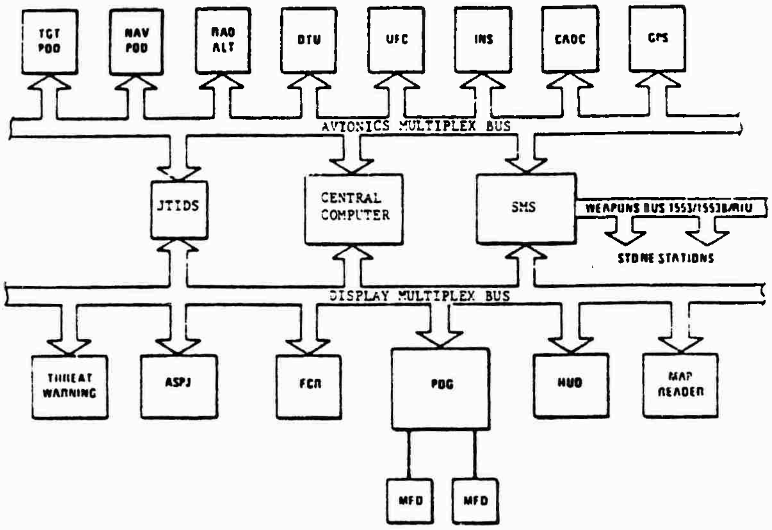

FIGURE 4. ADVANCED AIRCRAFT AVIONICS ARCHITECTURE

The integration of ICNIA into this avionic architecture is more straight forward than into the non-multiplex airplane. There are two reasons for this: (1) this avionics suite has the UFC which can control the ICNIA functions via the A bus and (2) the display system is more versatile.

The ICNIA integrated into the multiplex airplane is shown in Figure 5. The only non-Mux interfaces are with the audio, and a digital-to-analog converter which drives the analog Horizontal Situation Indicator (HSI) and Attitude Director Indicator (ADI) to display TACAN, ILS and VOR data. Actually, digitized audio could be transmitted via one of the buses in a 16Kbps Continually Variable Slope Delta Modulation (CVSD) format; however, this would require the design of a digital audio distribution system (Intercom).

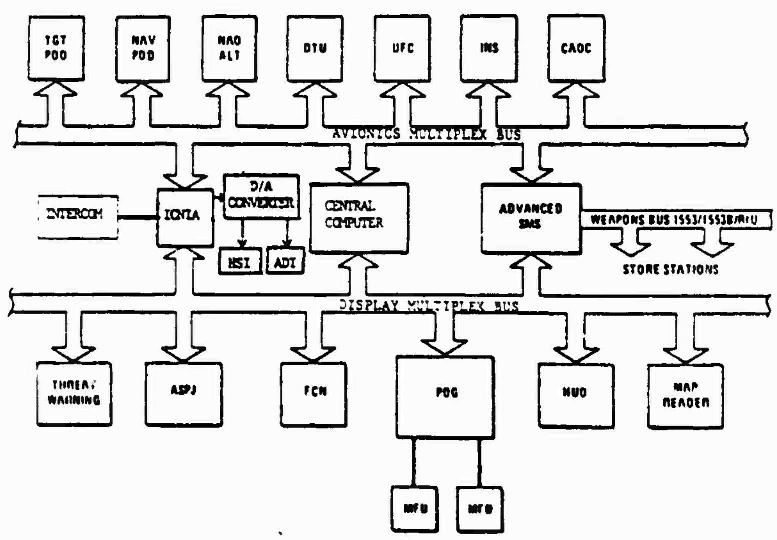

FIGURE 5. ICNIA INTEGRATION INTO ADVANCED AIRCRAFT

The signal flow on the A bus includes:

- o Navigation data to and from GPS
- o Navigation data to and from JTIDS
- o Control functions
- o Initialization data

The D bus carries CNI data to and from the PDG for display on one of the MFDs. It will carry display mode information from the MFD to JTIDS.

CONTROL AND DISPLAY

The aircraft crew interfaces with the ICNIA by three methods: (1) controls which determine the mode, frequency, etc. of the CNI functions, (2) displays which are a visual representation of the information derived from the CNI functions, and (3) audio from the voice receivers and to the voice transmitters, plus the audio identification of the navigation aid beacons. In the ICNIA design, the control and display signals are interfeced via a multiplex bus while each audio signal has its own port. The audio will interface diractly with the host eircraft intercom. However, the control and display functions will require some adeptetion in the non-multiplex aircraft while interfacing directly in the multiplex aircraft.

To provide ICNIA control in the non-multiplex eirplane three approaches are viable:

- o Retain the present CNI control panals. Convert the control signals to Mux format in the ICNIA adaptor.
- o Retain the present CNI control panels in their physical form but convert the internal circuitry to a Mux terminal.
- o Replece the prasent CNI control panels with an intagrated control panel with a Mux I/O.

With the first option, the control panels are retained. Thase panels hava a variety of I/O formats ranging from discretes to tailored sarial streams. Each panel is interfaced to an individual port on the ICNIA adaptor. The Adeptor converts the control panel signals to a Mux block format and transmits it to the ICNIA via the Mux. Feedback signals, where used, are sent from ICNIA to the Adaptor via Mux, converted into the control panel format and sent to the panel via its interface port. Such an architectura is shown in Figure 6.

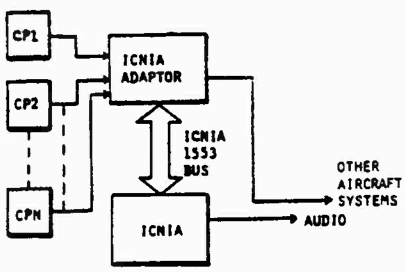

FIGURE 6. RETAINED CONTROL BOXES

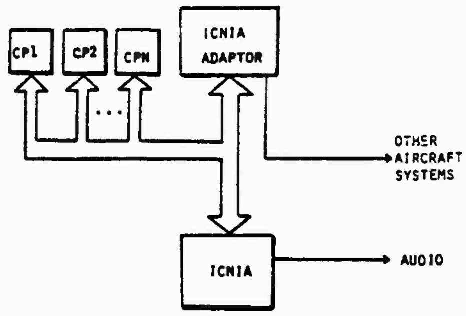

FIGURE 7. CONTROLS WITH MULTIPLEX TERMINALS

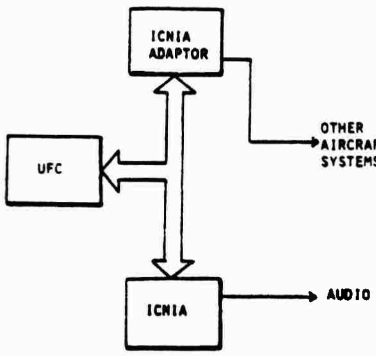

FIGURE 8. ICNIA CONTROLLED BY UFC

With the second option, the physical configuration of the control panels is unchanged. The internal circuitry is changed so that it formats control information in the ICNIA Mux format and sends it directly to the ICNIA via the Mux. This errangement is shown in Figure 7. Whila thesa control panels would closaly resemble thair individual aquipment counterparts, the circuitry would change completely to includa a mux tarminal and associated logic.

Tha third option would remove all CNI control panels from the cockpit end replaca them with e centrel control which communicatas with tha ICNIA via its Mux. All CNI functions ara than controlled from a single cockpit location. Tha UFC used in the multiplex architecture would fulfill tha requirement for a cantral CNI control. The UFC/ICNIA control architectura is shown in Figure 8.

JTIDS requiras soma form of situation display. Tha mannar of implementetion of this display is dependent on tha eirplana display system. If no existing display is availabla to tima shara with JTIDS, a naw dedicated display would ba raquired.

ANTENNAS

The prasent trend in tactical fighter aircraft toward smallar airframes and a greater number of electronic systems has resulted in an antenna location problem of a major magnitude. Simply stated, there just isn't enough room for all the antennas. The F-16 antenna locations shown in Figure 9 illustrate this. This problem is aggravated by the added functions of ICNIA. Each ICNIA function cannot have its own antenna system. Some functions must share antennas. The L-Band system, TACAN, IFF and JTIDS, being low-duty-cycle, pulse systems, can share the same antenna system if the proper transmitter-receiver coordination of these functions is included in the ICNIA. Other common frequency antenna integrations would be more difficult, such as UHF voice/glideslope/SATCOM and VHF voice/localizer/VOR. These integrations are more difficult because of transmitter high-duty cycles and antenna polarizations and are considered to be beyond the scope of this paper. However, it is recommended that an antenna integration program be implemented for these functions to alleviata the antenna location problem.

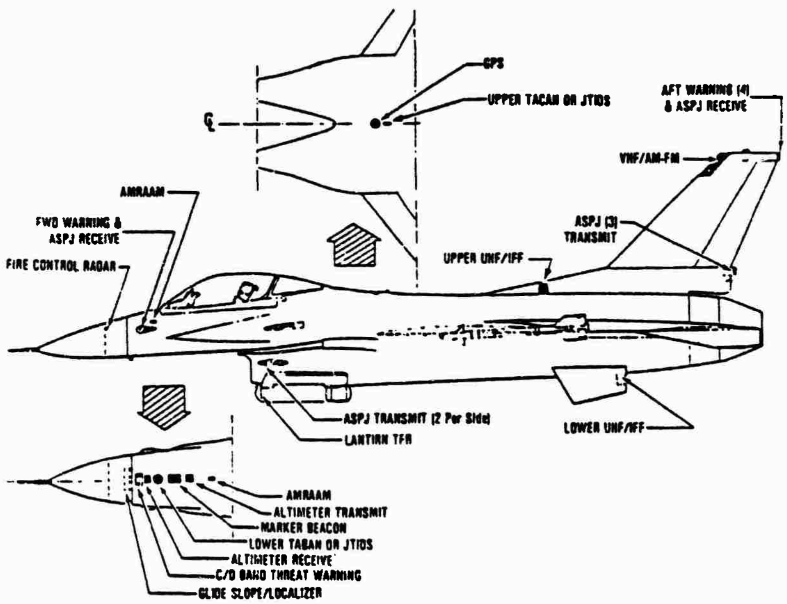

FIGURE 9. F-16 ANTENNA LOCATIONS

Tha HF function presents a uniqua antenna problem. HF antennas on small aircraft ara usually in the form of a notch in the vertical fin which excites tha entire airframe. The feedpoint impedance of this notch cannot remain constant over the nearly four octaves of the spectrum covered by HF. Therafore, an antenna couplar is raquired to present a constant load to the HF transmitter. The coupler must be located near the antenna faed and must be tailored to the particular airframe. It may also require frequency information from the ICNIA. Tha coupler such as that designed for the F-111 would operate with ICNIA, provided the ICNIA adaptor furnishes frequency information to the coupler.

SUMMARY AND CONCLUSIONS

The use of ICNIA will significantly improve the Avionics Suites of military aircraft. The advantagas of ICNIA includa:

- o Reduction in spaca, weight, power and cooling requirements;
- o Increase in reliability and maintainability;
- o Decreasa in Life Cycle Cost;
- o Ease of integration into an Avionics Suite via a multiplex bus, and
- o Reconfigurability.

However, to take advantage of these features, certain design guidelines should be followed. The basic guideline is that the airframer should control tha integration of any subsystem into his Avionics Suite. This implies that the ICNIA interfaca software, and possibly some of the hardware, must ba in accordance with tha integration philosophies of the host platform. These philosophies will vary from one host platform to the other. General Dynamics has an integration and partitioning concapt which has functioned exceptionally well on the F-16. ~~Simply stated,~~ Each subsystem should perform its entira task and the interfaces between subsystems should be as simple as possible. This concept has three major advantages:

- Changes to one subsystem are transparent to other subsystems and do not result in changes being required in other subeystems when one subsystem is changed.

- The integration of a new subsystem into the Avionics Suite is not difficult since a new system doee not require unique support of other subsystems. and

- Fault isolation is simple since each subsystem performe an entire task.

General Dynamics recommends that these characteristics be included in the ICNIA to be installed on the F-16. However, other airframers may have other interface requirements. Thus, a platfotm unique interface may be needed in ICNIA in order to satisfy the requirements of each using aircraft. This may be in the form of either a platform unique software module or a unique hardware interface module along with the software module. The JTIDS Class 2 Terminal, for example, has a platform unique I/O Adaptor which contains the hardware to match audio impedances, instrument drive requirements, etc. along with the interface software which performs the I/O via the platform data bus.

A recent trend in new avionic systems is to provide "by-product functions". These are functions which are not the primary purpose of the equipment but rather a by-product of the function performed by the equipment. The use of theee by-product functions should not be forced upon the airframer. Each airframer has his philosophy on how best to fulfill the requirements of his aircraft and how well the by-product function will aid the aircraft mission.

One by-product which has been appearing in the equipments which perform a primary or by-product navigation function is the inclusion of a Kalman filter to mix navigation data from several sources to obtain a best estimate position. Since navigation data is usually filtered by the aircraft, this may result in two Kalman filters being mechanized in the avionics suite. This leads to a rather precarious situation in that the two filters may exchange correlated error information. If this happens one or both of the filters could cause errors and may become unstable. General Dynamics feels that the processing of navigation data from several sources is a systems function and should reside in the central processor. However, other aircraft systems integrators may not agree. Therefore, General Dynamics recommends that the architecture of ICNIA be such that the use of a Kalman filter in ICNIA can be at the option of the avionics systems integrator.

Since this paper has addreseed generic aircraft installations, no discussion of the physical characteristics has been included. Because of the odd shapes available in fighter aircraft equipment bays, ICNIA should be made up of standard sized modules which can be used as building blocks to form odd sized LRUs. Looking at future aircraft, a wholly modular avionics suite made of card racke with a few types of standard modules seems probable. The VHSIC and PAVE PILLAR projects support such a concept. The ICNIA design will fit these advanced concepts. The Very High Speed Integrated Circuits being developed by the Government will result in a chip set which will form a MIL-STD-1750 proceesor. This VHSIC chip set ehould be directly applicable to the eignal processor and the data proceesor.

The PAVE PILLAR project is preeently studying the architecture of advanced avionic syetems. ICNIA is actually a part of PAVE PILLAR and will be blended into it in the future. ICNIA, having the versatile multiplex I/O that it does, will integrate into either the eingle or hierarchical bus structure being advanced today.

Finally, ICNIA conforms with the avionic eyetem concepts of the future. This concept embraces the sensor (receiver-transmitter), signal processor, data proceeeor structure eet forth previously in this paper. Since all avionic functions can be modeled to this structure and since a etandard processor is forthcoming, all functions of an avionice system can coneiet of etandard processors and epecialized sensors. When this is accomplished, the LRUs of today can be replaced with card racks coneieting of standard processor carde and special sensor cards. As such, the entire avionics suite will be composed of racks of standard cards plus the special cards. The impact of thie concept on systems deeign, maintenance and logistics challenges the imagination.

ACKNOWLEDGEMENTS

The author thanks Captain Gary Pennant and Mr. Darlow Botha of AFWAL, Phil Craighead, Chief of Communications and IFF, at General Dynamics/Fort Worth Division, and Dan Kaylor, Engineer, at General Dynamice/Fort Worth Division, and Dr. Pete Camana of TRW, Inc. for their help and encouragement in the preparation of this paper.

DISCUSSION

R.Davies, Ca

The list of avionics CNI subsystems to be integrated into ICNIA included ILS and in general covered frequencies between 2 MHz and 2 GHz. As ILS is only "protected" by ICAO until 1995, should not ICNIA include MLS interfaces for 5 GHz azimuth and elevation information in this regard? The first MLS civil certified system easily fed signals into a "DDM" type ILS receiver through a 'C' band antenna and converter. New TRSB MLS, as covered by ICAO "SARPS", may be difficult to handle and ICAO appears to pay no regard to MIL Spec 1553B data bus requirements.

Author's Reply

The functions to be included in ICNIA are designated by the government sponsoring agency. It could well include MLS at a later date. My personal opinion is that MLS should be included. Processing of the MLS signals should offer no problem.

W.R.Johnson, US

How are receiver/transmitters operating on different frequency ranges (VHF, UHF, SHF, etc.) applicable to reassignment?

Author's Reply

The receiver/transmitters are divided into three types: L-band, VHF/UHF and HF. Therefore a failed type must be replaced by the same type, e.g. L-band for L-band.

COMPUTER AIDED CONSTRUCTION OF GROUND ATTACK MISSION PROFILES OVER EUROPEAN TERRAIN

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SUMMARY

The optimization of an air-to-ground weapon inventory must investigate the trade-off between the effectiveness of the weapons and the vulnerability of the delivery aircraft to opposing ground defences while flying the mission profile required by the weapon. The Directorate of Air Operational Research within the Canadian Department of National Defence has developed a computerized technique for describing and constructing air-to-ground mission profiles in relation to actual terrain. The aim was to develop a profile construction system that permits the user to accurately but concisely direct the construction process. The technique relies on computer graphics to assist the user in creating realistic attack profiles. The system employs a data base of digitized central European terrain to produce perspective terrain image snapshots at key positions in the profile.

Post analysis of the exposure history of a given profile will allow a reasonable assessment of the comparative survivability of an aircraft having to deliver weapon type A versus its survivability when delivering weapon type B. Although designed for use in weapon mix determinations for the Canadian Forces, this analysis tool may have useful applications in both aircraft design and air-to-ground weapon design for low level ground attack missions.

INTRODUCTION

The Canadian Forces are in the process of acquiring a new fleet of 138 CF-18A fighter aircraft. The purchase of an updated inventory of air-to-ground weapons for use with the CF-18A is being considered. The Directorate of Air Operational Research has been tasked to develop analytic tools to assist in the selection process.

The primary trade-off against the destructive effectiveness of an air-to-ground weapon is the vulnerability of the aircraft to ground defences while flying the required weapon delivery profile. The models described in this paper were developed to assist in the assessment of the relative vulnerability of specific delivery tactics.

Aircraft vulnerability at low altitude is directly dependent on the terrain. If terrain is simulated or characterized, and analysis proceeds on this basis, then the results would involve uncertainties that would be impossible to quantify. Consequently the decision was made at an early stage to employ real terrain (digitized and supplied courtesy of the Defense Mapping Agency in the United States).

The first step in the modelling process is to develop a system for describing and constructing realistic ground attack flight profiles in relation to the terrain. A machine-readable record of the profile is the end product. There is a complete spectrum of possible modelling approaches to accomplish this task. Section 1 describes the details of the model that was developed and the rationale behind the selected approach. The model is entitled GAPS II, an acronym for Ground Attack Profile Selector program (version II).

The next step towards assessing aircraft vulnerability is the adoption of intervisibility algorithms so that the existence or non-existence a line-of-sight between a ground defensive position and the aircraft can be determined. The end product of the intervisibility evaluation is an "exposure history" - a tabulation of all key parameters, from the point of view of the defensive position, that will affect the ability of the air defence equipment to engage the aircraft. Sections 2 and 3 of this paper describe the modelling efforts that bring the process to the "exposure history" stage.

Future work on this project will be directed towards a numerical evaluation algorithm for the relative vulnerability assessment of different exposure histories. The term "relative" in the preceeding sentence is important. Vulnerability in absolute terms - in the form of a probability of kill or an attrition rate - is considerably more difficult to model with an acceptable level of accuracy. Since the project's objective is to compare different air-to-ground weapons to each other, then a less complex comparative methodology will be sufficient.

1. THE GROUND ATTACK PROFILE SELECTOR (GAPS II) PROGRAM

The development objective of the GAPS II system was to devise a method of creating and recording a realistic ground attack profile in relation to actual terrain. The construction process should be accurate but concise; a process that a person with fighter pilot experience could feel comfortable with, so that maximum realism can be transmitted to the resulting profile. Accuracy and conciseness are in general conflicting objectives, so careful selection of the modelling approach is necessary.

One approach would be to directly simulate the aircraft aerodynamics, accepting stick, throttle, etc. inputs and integrating the equations of motion to determine future positions for the aircraft. This method would produce very realistic profiles. However it would involve a heavy computational load and a large data base for every aircraft to be simulated, not to mention a considerable development effort for the software.

Another approach would be to forego all aircraft-related parameters entirely and simply specify directly a path of (X,Y,Z) positions as a function of time to be the desired profile. This method permits accurate location of the profile in relation to the terrain. However, it could easily and unknowingly produce results that imply manoeuvres that are in fact outside the capability of the airframe to generate. Also, the construction process would be very tedious for all but short profiles.

The two approaches described above represent opposite ends of the modelling spectrum. The approach that was selected for GAPS II lies between these two extremes, and is described as follows.

A profile is defined by a series of flight <u>segments</u>. The final position and velocity vectors of a segment are identically the initial vectors for the next segment. Four parameters define the segment. The first is the <u>linear acceleration</u>. It always acts in the direction of the instantaneous velocity vector to produce speed changes. The second parameter is <u>lateral acceleration</u>, which always acts perpendicularly to the instantaneous velocity vector. Lateral acceleration defines the aircraft turn rate. Both of these accelerations have a constant magnitude during the segment. The third parameter is an <u>angle</u>, defining the plane on which the lateral acceleration will take place. The fourth is the segment duration <u>time</u>.

The above four parameters are sufficient to define a unique flight segment. The solution of the equations of motion is considerably more straightforward if gravity is removed from the problem. This assumption not only simplifies the mathematics, but also makes it easier for the flight profile constructor to guide the aircraft across the terrain. With gravity removed there are no extraneous forces acting on the two specified acceleration values.

The locus of points described by the aircraft during a single flight segment is two-dimensional. The lateral acceleration parameter acts in a plane whose orientation is specified by the third segment parameter, which is called the "bank" angle. This angle is defined in relation to the aircraft velocity vector at the beginning of the segment and the positive Z (vertical) axis. The combination of lateral acceleration and "bank" angle relates directly to the way an aircraft will roll and then initiate a positive g-load to conduct a turn. The actual bank angle on a real aircraft performing the manouevre would be slightly different since the real aircraft would also have to deal with gravity - hence the quotation marks.

Appendix A details the mathematical solution to the equations of motion summarized from Ref. (1). Given the position and velocity vectors at the beginning of the flight segment and the linear acceleration, lateral acceleration and "bank" angle values, one can directly calculate the position and velocity vectors at any subsequent point in time.

The segment is terminated at a given time. This time may be specified directly or it may be implied by five other terminal constraints: on distance travelled, speed acquired, altitude reached, heading acquired or climb angle attained. Some of these termination variables can be directly converted to time (e.g. distance or speed). For the remaining variables it is necessary to step through time in short intervals and identify the segment duration time iteratively.

The mechanism by which the ground attack profile is constructed has now been laid down. This mechanism must now be encased in an interactive, automated framework that will enable accurate and efficient construction of the profile in relation to the terrain.

It was recognized at an early stage in the project that the assistance of computer graphics would be essential in developing an efficient system. Production of a perspective snapshot of the terrain in front of the aircraft, as it would be viewed from the cockpit at that instant, would provide instant feedback to the profile constructor. He quickly can verify that a selected segment in fact produced the desired result. Accuracy is enhanced and maximum realism can be passed on to the constructed profile. Consequently, a Tektronix 4054 Graphics system was acquired. This is a desktop computer, programmable in BASIC, with a high resolution CRT (storage scope as opposed to raster-scan). Maximum memory (64K bytes) and a flexible disk drive are required options. The GAPS II program is written in BASIC for this hardware system.

Before progressing further, a description is given of the terrain data base and its application with GAPS II. The Defense Mapping Agency (USA) product used covers the region illustrated in Figure 1: 49 to 51 degrees north and 10 to 14 degrees east. This portion of central Europe was digitized on a grid every 3 seconds of arc in both latitude and longitude. Elevations are recorded to the nearest 3 meters.

For use in GAPS II, it was found that a 3 second by 3 second grid produced too dense a terrain image, so the data was thinned to every 6 seconds in both latitude and longitude. To facilitate handling of the data on flexible disks, it was subdivided into 20 minute by 20 minute blocks as demonstrated in Figure 1. Each block contains 40000 elevations. The data within each block is stored in duplicate, so that it can be directly accessed in records of constant latitude or records of constant longitude.

Production of a "snapshot" of the terrain from the aircraft's position is accomplished by drawing strings of elevations from the terrain data base and projecting them appropriately onto the graphics screen in a checkerboard pattern. To simplify the projection calculations and to be consistent with the conciseness mandate of the profile construction system, a "flat earth" assumption was made. The terrain data is projected onto a rectangular grid with longitudinal compression based on the cosine of the mean data latitude (50°). Note that for the purposes of constructing a flight profile in relation to terrain, the slight curvature of both the terrain and the profile over long distances is not really relevant. It is the short range relationship between aircraft and terrain that is of significance. However, for the purposes of assessing exposure of the aircraft to ground defences over moderate to long ranges, the earth's curvature is significant. Hence suitable corrections for earth's curvature are made at that stage.

Figure 2 presents a sample of the terrain imagery that GAPS II will produce. The 6 second by 6 second grid projects to rectangles approximately 185 m north-south by 119 m east-west. Note that those edges or portions thereof that are hidden by intervening foreground terrain are not drawn. In fact the algorithm that determines which edges are visible and which are masked constitutes the majority of the image rendering software. Appendix B lays out the projection equations and describes the terrain masking algorithm in detail.

The GAPS II program consists of over 1300 lines of BASIC code. The software is modularized to take advantage of the user-definable key (UDK) feature of the machine. Each of the 20 UDKs, when selected, executes a routine to accomplish a specific task. For example, one UDK begins construction of a new profile segment. Another key will produce the terrain image as viewed at the endpoint of the current segment. Other UDKs will list sets of relevant parameter values for reference, or allow one of the four segment-defining parameters to be refined. Other utility routines will: permit the viewport to be changed; allow the terrain disk to be changed; enable the user to step back in time by deleting any number of the most recent segments; note the weapon release time; terminate the profile construction; and even change the hardware character size being used. Note from Figure 2 that the left hand portion of the screen is reserved for text. This modularized software approach allows the user to define the execution stream as the profile construction proceeds. One is often refining flight segment parameters to produce a precise manoeuvre, so this approach suits the "hit and miss" nature of the construction process.

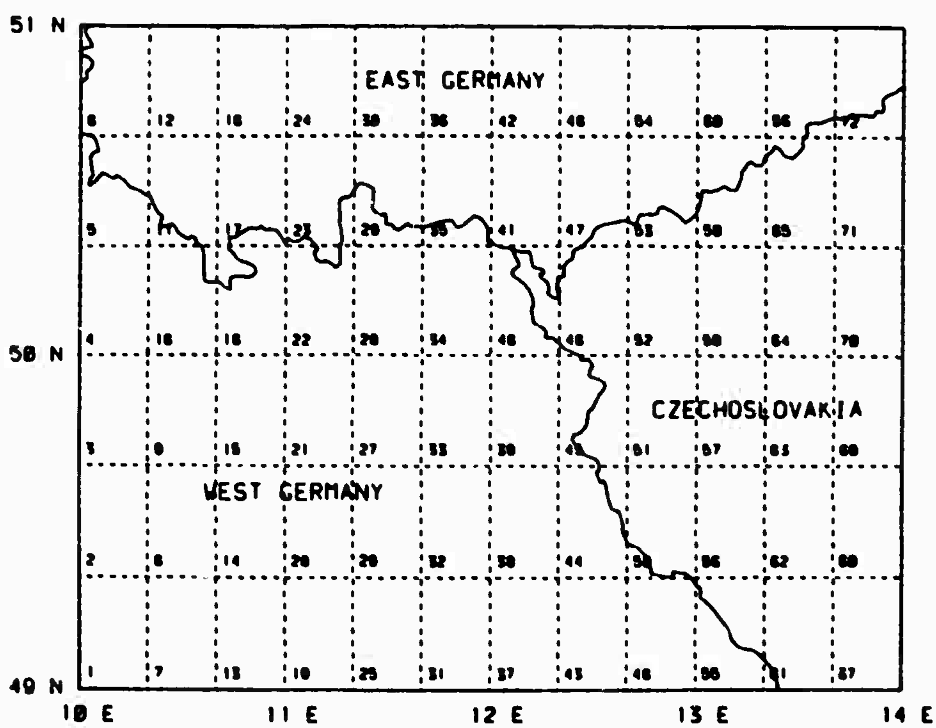


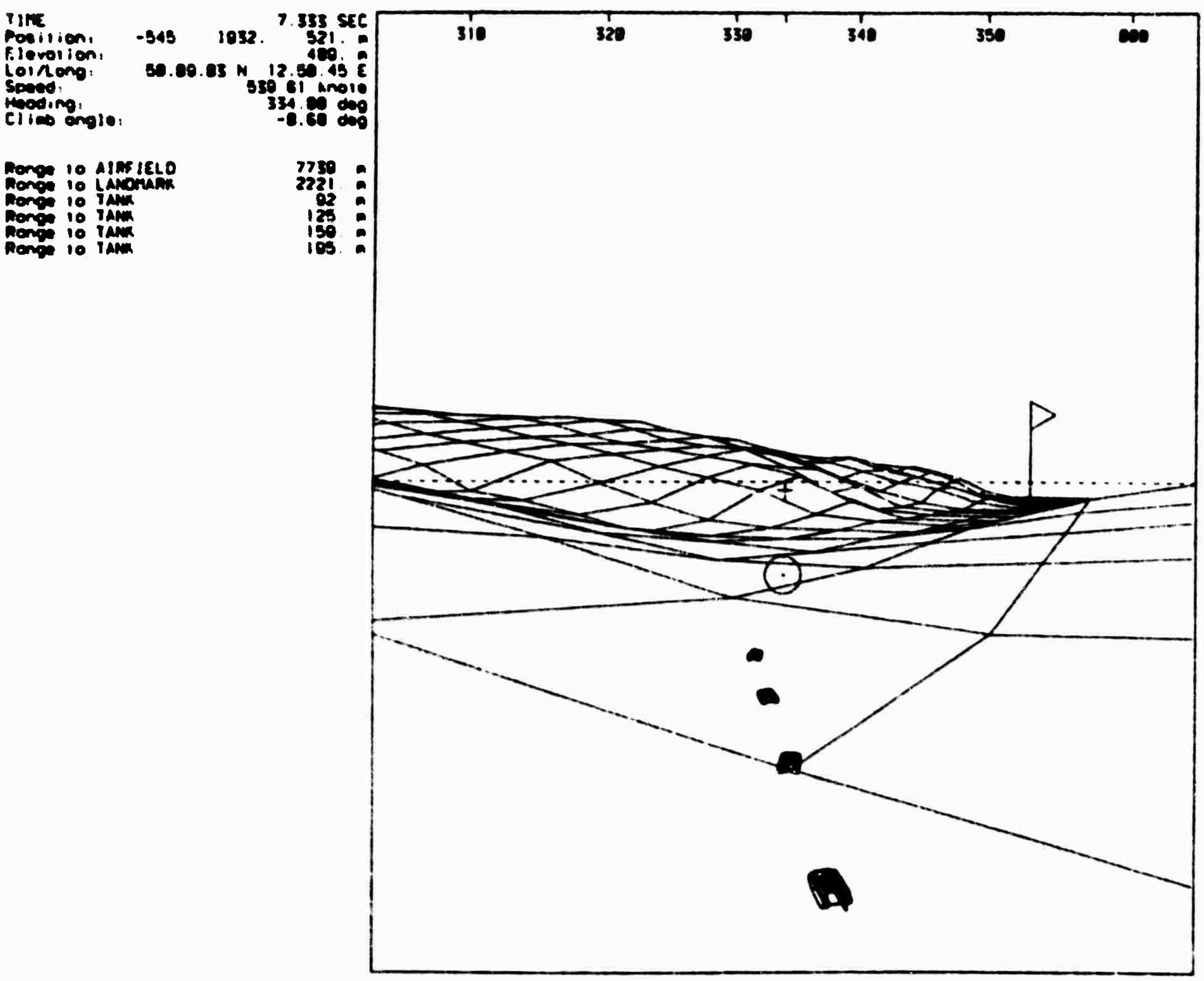
FIGURE 1

DIGITAL TERRAIN CURRENTLY AVAILABLE TO GAPS II

Observe also from Figure 2 that there are several objects superimposed upon the terrain image. The purpose of these objects is twofold. First, they can be located at selected geographic positions as landmarks, to be used as navigation aids. Secondly, they can be drawn to represent the target objects of the air-to-ground mission. Also presented on the image in Figure 2 is a horizon reference line (dashed line), a velocity vector indicator (cross "+") and a bomb-sight (2 mil and 50 mil concentric circles). Co-ordination of the above visual cues permits accurate alignment of the aircraft during manoeuvres leading up to the weapon release point.

The image depicted in Figure 2 will take of the order of a minute or two to produce on the Tektronix hardware. The machine is not capable of producing real time imagery and GAPS II is not designed to interact in real time, hence it should be emphasized that GAPS II is <u>not</u> a flight simulator. The graphic imagery is produced simply as a snapshot to verify the conditions at the end of any segment within the flight profile. For the purposes of demonstrating the GAPS II system, however, a temporary modification was made that allowed the program to automatically step through a pre-constructed profile and take hard-copy reproductions of these images at short time increments during the profile. The resulting stack of paper was animated into a one minute film clip by the Canadian Forces photo unit.

A transportable and complete record of the flight profile must be the end product from GAPS II. Recorded for each segment of the profile are: the position and velocity vectors at the segment start and end points; the linear acceleration, lateral acceleration and "bank" angle parameter values that apply during the flight segment; and the time at the start and end points. Also recorded are necessary global parameter values such as the latitude and longitude of the profile start point and the time of weapon release. Along with this data file goes a short software routine called ENDPOINT, which automates the equations in Appendix A. This routine permits the above data file to be interpolated, so that the position and velocity vector at any point in time during the profile can be calculated. This format for the GAPS II end product was considered more practical than a length history of position and velocity at fine time intervals. GAPS II is documented in detail in Ref. (2).



<u>FIGURE 2</u>

<u>SAMPLE OF GAPS II IMAGERY</u>

2. ASSESSMENT OF INTERVISIBILITY

The GAPS II model produces a flight profile in relation to the digital terrain. The next step is to determine how exposed this profile would be to selected defensive positions.

Consider a piece of air defence equipment at a specific geographic position and sitting on the terrain. The sensing component (e.g. eyeball, antenna, etc.) is located at some height above the ground. The first step in the exposure assessment process is to develop a method of determining, at any point along the flight profile, whether or not a line of sight exists between the aircraft and the sensor. The height of the terrain between the two points and the earth's curvature factor applicable to the electromagnetic frequency of operation of the air defence gear will determine intervisibility. Vegetation or cultural features are not included in the intervisibility determination.

Two approaches for intervisibility calculation were considered. The first was to produce a routine that would operate on the GAPS II data file for the profile and the digital terrain data base. For each pair of aircraft and sensor positions it would determine the intervisibility status. The second approach was to process all the terrain in the vicinity of a defensive site one time only. The product would be a secondary data file that recorded, at each grid position in this region, the altitude (ASL) below which the aircraft is not visible from the defensive position. Call this altitude the <u>shadow height</u> at that location.

The first approach is a "pay-as-you-go" method. No initial processing is required, but a cumbersome sequence of calculations (with data handling problems) is required for each intervisibility assessment. This approach was selected for the model described in Ref. (3). The second approach has the disadvantage of a large initial expenditure of computer resources. However once the shadow height file has been established, then any point on any profile that passes through the region can be assessed quickly as being visible or not from that defensive site. All that is required is a simple interrogation of this secondary file.

The second approach was selected, as it appeared that it would be the most efficient method to use over the run of a long multi-scenario analysis. A piece of FORTRAN software labelled AVIS (for Aircraft VISibility) produces the shadow height file. Inputs to the program include: the latitude and longitude of the defensive site; the height of the sensor above ground; the radius of the area of interest about the site; and the effective earth radius to be applied in the curvature corrections.

Before processing of the digital elevation data takes place, the curvature correction factor, $1000D^2/2R$, is subtracted from the ASL elevation value at each terrain grid point in the region of interest. Parameter D represents the distance from the defensive site to the grid position and R is the effective earth radius (both in km). The AVIS program then operates on the corrected elevation values radially outward from the defensive site. By employing a shadow casting technique, the shadow height at each grid point can be calculated. The technique is straight forward and described in detail in Ref. (4). The most difficult facets of the AVIS program in fact are the data handling problems and switching from processing latitude contours to processing longitude contours and back.

Figure 3 illustrates a sample cross-section of the digital terrain (compressed considerably in the horizontal direction). A defensive site is positioned at the asterisk. The bold line represents the shadow height values as calculated by AVIS. Since the terrain is drawn as "flat earth", the curvature corrections are reflected in the slight upwards bowing of the shadow height curve.

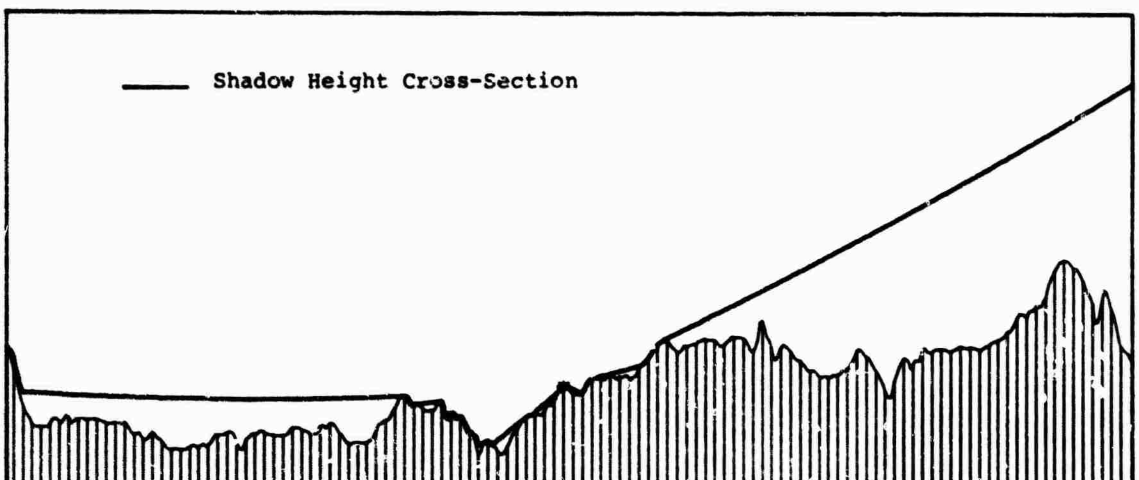


FIGURE 3

ILLUSTRATION OF INTERVISIBILITY CALCULATIONS

3. DETERMINATION OF EXPOSURE HISTORY

Given a flight profile produced via GAPS II and a file of shadow heights generated about a selected defensive site by AVIS, the next step is to merge these two products into to what shall be called an exposure history. The exposure history is a record, from the point of view of the defensive site, of the important parameters affecting the site's ability to engage the target aircraft.

A FORTRAN program named MERAGE (acronym for "Merge AVIS and GAPS II") was developed to produce this record. The flight profile is sampled at a regular time interval. At each point the following quantities are recorded:

1. time (from profile start)
2. range to aircraft
3. aircraft bearing from defensive site
4. aircraft altitude above sea level
5. aircraft height above shadow height (negative if below)
6. velocity vector of aircraft.

From this exposure history file, key variables affecting engagability can be calculated. Examples are the radial velocity and angular velocity of the aircraft with respect to the defensive site, and the angle of the aircraft above the highest point of intervening terrain. The workings of the MERAGE program are documented in Ref. (5).

As an example of typical exposure histories, consider the two air-to-ground profiles shown in Figure 4. The terrain illustrated is a small section of central Europe. An airfield was identified as a suitable target. The bold line represents a profile delivering BL-755 cluster weapons. The aircraft passes directly over the airfield at approximately 100 m AGL. The profile represented by the fine line adopts a shallow pop-up manoeuvre to accomodate a CRV-7 (2.75 inch) rocket launch at a five degree dive angle and 3000 metres slant range. Ingress and egress of both profiles are at 100 metres AGL on average. These profiles were planned and "flown" by a CF-104 pilot using the GAPS II system. Incidently the grey-scale relief background of Figure 4, on which the two profiles are illustrated, was also produced by the Tektronix high-resolution graphics system. Dark shades represent high elevations.

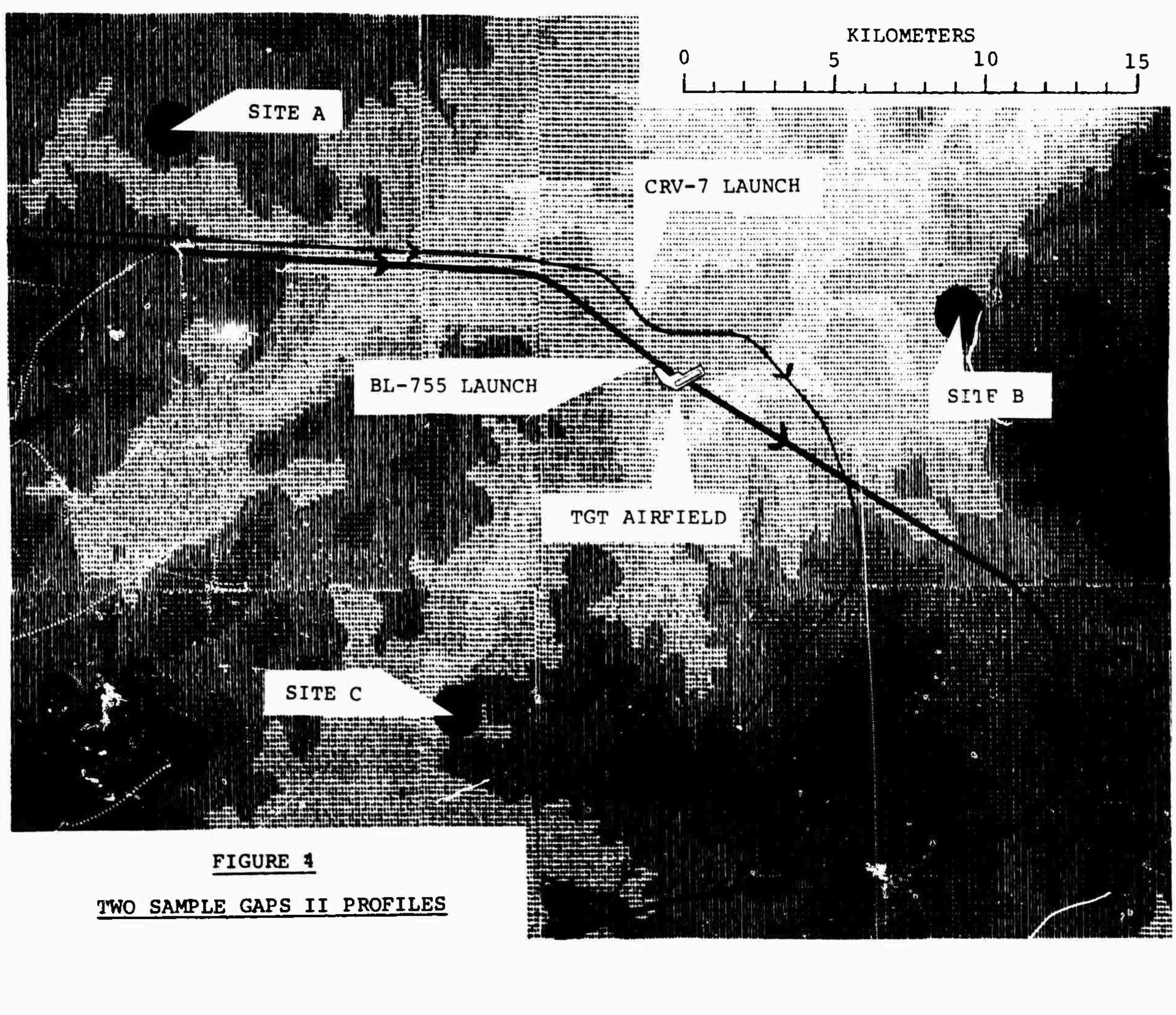


FIGURE 4

TWO SAMPLE GAPS II PROFILES

Three sites for air defence, arbitrarily selected within this region, are illustrated in Figure 4. AVIS runs at these locations were made based on an antenna height of 5 metres and a maximum detection range of 18 kilometres. The MERAGE program merged each combination of defensive site and profile to produce the exposure history data file.

Figures 5(a) and 5(b) illustrate the visibility of the CRV-7 and BL-755 delivery profiles (respectively) from each of the three defensive sites. When the aircraft is visible from a given site, a straight line is drawn to join the two positions in the figure. The resulting fan-shaped regions identify the visible portions of each profile.

A graphical summary of the exposure history of each profile from the point of view of defensive site B is shown in Figure 6. Four charts displaying key parameter values as a function of time are presented. The curves drawn on the right side represent the BL-755 delivery profile and the curves on the left apply to the CRV-7 profile.

The top graph in Figure 6 shows the radial velocity, equivalent to radar frequency doppler shift, that site B will see as a function of time. Near zero values of radial velocity will hamper the ability of doppler radars to detect or track the aircraft.

The second graph shows the horizontal angular velocity of the aircraft in relation to the site. This parameter is the slewing rate that an antenna servo system would have to deliver in order to be able to track the aircraft. If the demanded rate approaches or exceeds the hardware limit then tracking ability will be affected.

The third graph displays range to target as a function of time. Range affects detectability and weapon flight time, and will be a key variable for any air defence system.

The parameter displayed in the bottom figure is labelled "angle above terrain". This is the vertical angle subtended at the defensive site between the aircraft position in the sky and the highest point of land between the two positions. This angle affects phenomena such as radar clutter and multi-pathing. Radar detection and tracking is degraded at small angles above the terrain. Obviously, if this angle becomes negative then the aircraft is masked completely by the terrain.

The models developed by the Directorate of Air Operational Research to date bring the vulnerability assessment to this exposure history stage. The next step, and it is a large one, is to develop an effectiveness model to quantify the vulnerability of individual exposures in a reasonable and not-too-complex way. As was mentioned in the introduction, the methodology need only be sufficiently complex to permit a reasonable <u>comparative</u> vulnerability assessment. It is envisioned that "cookie cutter" limits on the key parameters (for example, the four parameters depicted in Figure 6) will be used to identify engageable exposures. Simple weapon fly out routines can be used to model the guidance laws of the system. Figures-of-merit such as "maximum number of missile engagements" will be the bottom line.

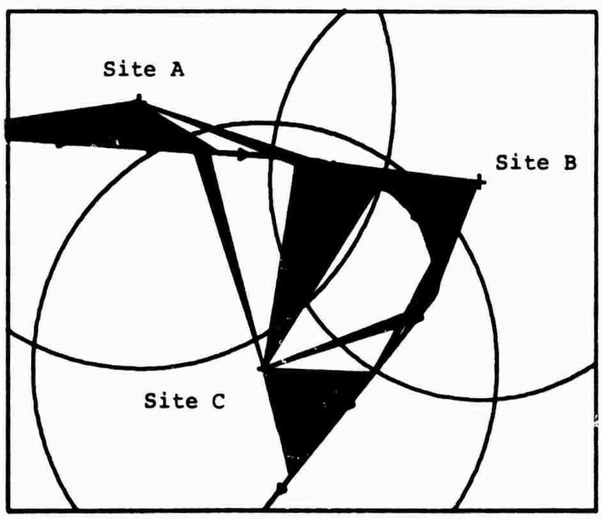


FIGURE 5(a)

EXPOSURE OF CRV-7 DELIVERY PROFILE

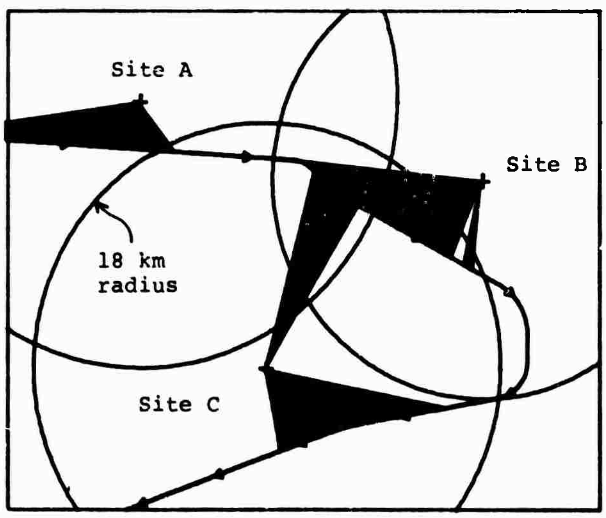


FIGURE 5(b)

EXPOSURE OF BL-755 DELIVERY PROFILE

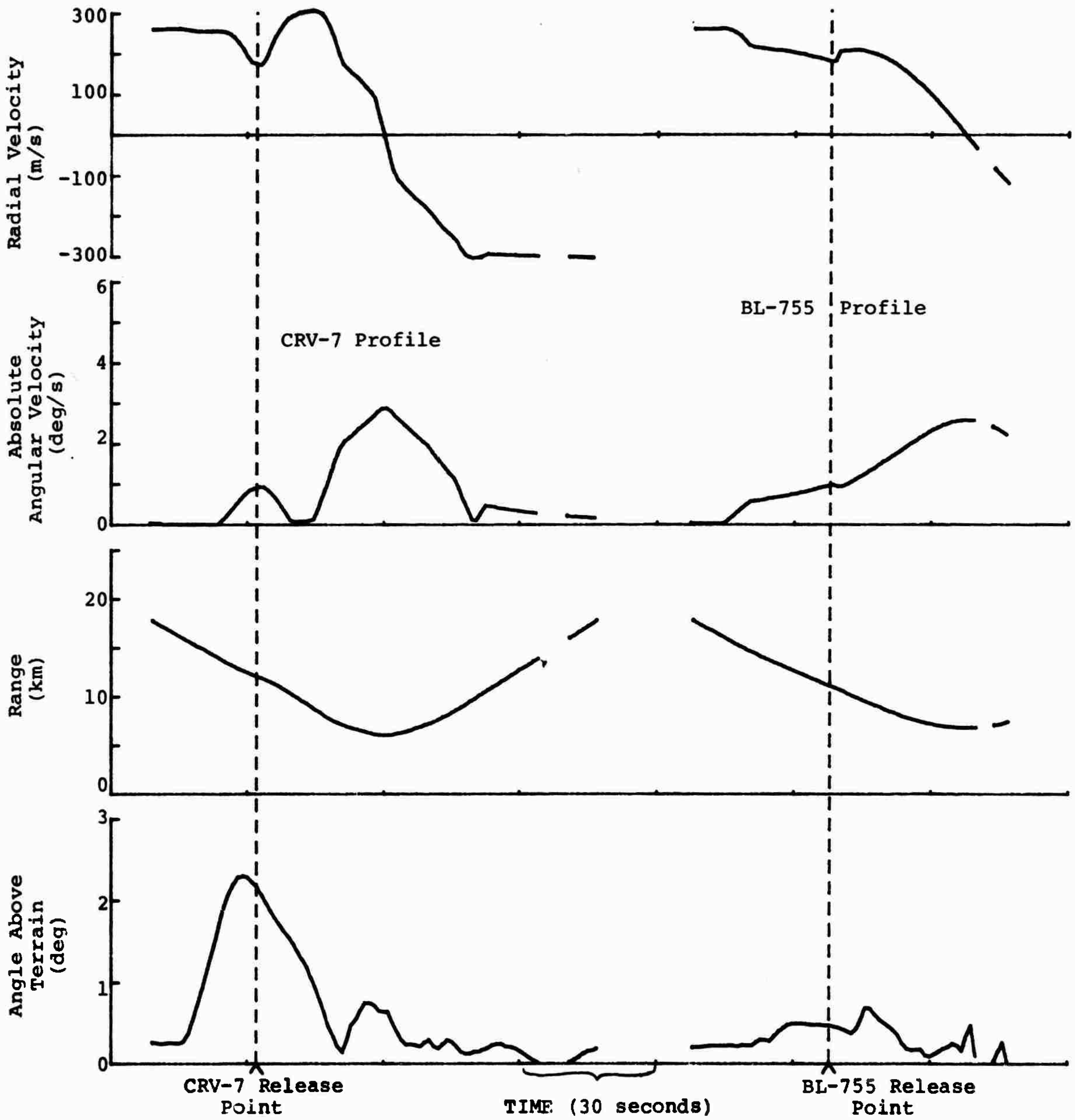


FIGURE 6

GRAPHICAL SUMMARY OF KEY EXPOSURE PARAMETERS

REFERENCES

1. MASON, D.W., Directorate of Air Operational Research (Can.); The Ground Attack Profile Selector Program; October, 1979, Staff Note 79/11.

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3. WEGNER, L.W. and M.G. Weiner, RAND Report; The Terrain Intervisibility and Movement Routine (TIMER) Model; January, 1979, R-2376-ARPA.

4. MASON, D.W., Directorate of Air Operational Research (Can.); AVIS - An Algorithm to Determine Aircraft to Ground Site Intervisibility Using Digitized Terrain Data; March, 1980, Staff Note 80/4.

5. SAUNDERS, P.H., Directorate of Air Operational Research (Can.); The Merging of AVIS and GAPS: A Merage Made in DAOR; November, 1982, Staff Note 82/11.

MATHEMATICAL CONSTRUCTION OF THE FLIGHT PROFILE

The flight profile is assembled as a series of segments. Given the terminal velocity and position vectors from the previous segment, four inputs - linear acceleration, lateral acceleration, "bank" angle and segment duration time - are used to define the next segment of the aircraft path. We wish to solve the equations of motion to obtain an expression for the position vector (X(t), Y(t), Z(t)) and the velocity vector $(V_X(t), V_Y(y), V_Z(t))$ at all times t during the segment duration.

The solutions are more easily derived in two stages. The first stage solves the equations of motion in a simplified two dimensional situation, using only the acceleration parameters and duration time. The second step consists of rotating and translating this constructed segment into the appropriate position in three dimensions defined by the segment's initial conditions and the bank angle parameter.

The problem is scribed two dimensionally as follows, with lower case x and y representing the 2-D situation. The vehicle commences at the origin at t=0 with initial velocity v_0 directed along the x-axis. The linear acceleration parameter, a_v (v for velocity), is of constant magnitude during the segment and is always in the direction of the velocity vector. The lateral acceleration, a_p (p for perpendicular), is of constant magnitude during the segment also and is always directed perpendicular and to the left of the velocity vector. The angle θ is defined as the deflection of the velocity vector from the original x-axis direction. The equations describing this situation are

$$v(t) = v_0 + a_v t \tag{A1}$$

$$\frac{d\theta(t)}{dt} = a_p/v(t) \tag{A2}$$

Substituting (A1) into (A2) and integrating yields

$$\theta(t) = (a_p/a_v)\ \ell n\ (1 + a_v t/v_0) \tag{A3}$$

The velocity components at time t are then

$$v_x(t) = \frac{dx(t)}{dt} = v(t)\cos(\theta(t)) \qquad \text{(A4)}$$

$$v_y(t) = \frac{dy(t)}{dt} = v(t)\sin(\theta(t)) \qquad \text{(A4)}$$

Hence

$$x(t) = \int_0^t (v_0 + a_v s)\cos\left[(a_p/a_v)\ \ell n\ (1 + a_v s/v_0)\right]ds \tag{A6}$$

$$y(t) = \int_0^t (v_0 + a_v s)\sin\left[(a_p/a_v)\ \ell n\ (1 + a_v s/v_0)\right]ds \tag{A7}$$

Substituting a change of variable

$$Z = (a_p/a_v)\ \ell n\ (1 + a_v s/v_0) \tag{A8}$$

and using the known integral

$$\int e^{gx}\cos x\,dx = (e^{gx}/(g^2 + 1))(g\cos x + \sin x) \tag{A9}$$

produces the solution

$$x(t) = \left[(v_0+a_v t)^2(2a_v\cos(\theta(t))+a_p\sin(\theta(t))-2v_0{}^2a_v\right]/(4a_v{}^2+a_p{}^2) \tag{A10}$$

$$y(t) = \left[(v_0+a_v t)^2(2a_v\sin(\theta(t))-a_p\cos(\theta(t))+v_0{}^2a_p\right]/(4a_v{}^2+a_p{}^2) \tag{A11}$$

The second operation is that of rotating and translating this two-dimensional curve into its appropriate position in three dimensions. This manoeuvre identifies the terminal position and velocity vectors from the previous segment as the initial vectors for this segment (denoted $\vec{C}$ and $\vec{V}$ respectively), and requires the input of one other parameter to establish the curve's position now that there is one more degree-of-freedom in the coordinate system.

This parameter is called the "bank" angle. It specifies the plane in which the lateral acceleration takes place and is defined in more detail as follows. Consider the aircraft at the segment's initial position and velocity conditions with the wings parallel to the ground. Let $\vec{N}$ be the vector pointing directly up through the cockpit of the aircraft normal to the plane defined by the velocity vector and a line joining the wing tips. Vector $\vec{N}$ is then rotated about the aircraft's velocity vector to the "bank" angle. Positive rotation is clockwise from the pilot's point of view. The path of the aircraft during the segment will lie in the plane defined by $\vec{V}$ and $\vec{N}$. As mentioned in the introduction, the term "Bank" angle very nearly represents the actual angle of bank of the wings of an aircraft in flight, the difference being that the actual angle of bank has to account for gravity.

Note that with zero lateral acceleration, $\vec{V}$ will not change in direction. Hence no bank angle input is required. Note also that if the aircraft were flying straight up or down, the reference position of wings being parallel to the ground becomes ambiguous and the bank angle is undefined. The GAPS II program prohibits vertical flight as the initial conditions of any segment, however the aircraft is permitted to pass through such a condition during a segment.

The second phase of the construction then is to imbed the (x,y) plane into the (X,Y,Z) space and apply the proper rotational and translational operations. It can be shown without too much difficulty that the solution for the coordinate vector at time $T_i + t$ is

$$\begin{bmatrix} X(T_i+t) \\ Y(T_i+t) \\ Z(T_i+t) \end{bmatrix} = \begin{bmatrix} X(T_i) \\ Y(T_i) \\ Z(T_i) \end{bmatrix} + \begin{bmatrix} [V_X/V] & [-(V_XV_Y/SV)\cos\gamma + (V_Y/S)\sin\gamma] \\ [V_Y/V] & [-(V_YV_Z/SV)\cos\gamma - (V_X/S)\sin\gamma] \\ [V_Z/V] & [(S/V)\cos\gamma] \end{bmatrix} \begin{bmatrix} x(t) \\ y(t) \end{bmatrix} \tag{A12}$$

where the velocity vector at the segment start time, T_i, has been abbreviated to (V_X,V_Y,V_Z). Also in (A12) V represents the speed at time T_i, γ is the "bank" angle parameter, $S = (V_X{}^2+V_Y{}^2)^{1/2}$, and x(t) and y(t) are as defined in (A10) and (A11) respectively. Let C represent the aircraft coordinate vector and M represent the transformation matrix in (A12). The position and velocity vectors at any time during the segment are then:

$$\vec{C}(T_i + t) = \vec{C}\ (T_i) + M \begin{bmatrix} x(t) \\ v(t) \end{bmatrix} \tag{A13}$$

$$V(T_i + t) = M \begin{bmatrix} v_x(t) \\ v_y(t) \end{bmatrix} \tag{A14}$$

where $v_x(t)$ and $v_y(t)$ are as defined in (A4) and (A5).

APPENDIX B

TERRAIN DISPLAY ALGORITHMS

This appendix addresses the techniques and algorithms used to generate the type of terrain displays illustrated in Figure 2 of the main text of this paper.

The following equations will produce a perspective projection from three to two dimensions, $(x,y,z)\rightarrow(x',y')$, and can be directly derived from basic principles.

$$\begin{bmatrix} x^* \\ y^* \\ z^* \end{bmatrix} = P \begin{bmatrix} x - C_x \\ y - C_y \\ x - C_z \end{bmatrix} \tag{B1}$$

$$\begin{aligned} x' &= x^*W/(-z^*) \\ y' &= y^*W/(-z^*) \end{aligned} \tag{B2}$$

where

$$P = \begin{bmatrix} V_y/S_2 & -V_x/S_2 & 0 \\ -V_xV_z/(S_2S_3) & -V_yV_z/(S_2S_3) & S_2/S_3 \\ -V_x/S_3 & -V_y/S_3 & -V_z/S_3 \end{bmatrix} . \tag{B3}$$

The aircraft's current position is (C_x,C_y,C_z) and the aircraft's current velocity vector is (V_x,V_y,V_z). Also

$$S_2 = (V_x^2+V_y^2)^{1/2}$$
$$S_3 = (V_x^2+V_y^2+V_z^2)^{1/2}$$

The parameter W represents the distance to the projection plane from the aircraft.

The most logical approach in creating the terrain scene is to display the foreground information first and work progressively out to the horizon. This tactic in fact is necessary in order to be able to implement terrain masking. It also permits the user to control (interactively) how far into the distance the terrain is to be drawn. The terrain data must be displayable from near to far looking in any compass direction - a constraint that imposes two major conditions on its accessibility. First it must be accessable both through records of constant latitude and records of constant longitude. Secondly these records must be accessable, in sequence, in both forward and backward direction.

These conditions are not a problem if the entire terrain matrix can be held within the machine's memory. The limited memory of the Tektronix 4054 (64K bytes), however, does not permit a sufficiently large portion of terrain to be retained internally, so the terrain data is accessed via random access files on the flexible disk file manager. In order to have the data accessible in both north-south and east-west directions the data must be stored in duplicate. On the file named "LATITUDES", the elevations within an individual data record run from west to east at a constant latitude, with successive records running northward. The same data is held in the file "LONGITUDES" but it is ordered orthogonally. Data records on this file contain elevations running from south to north at a given longitude with successive records progressing eastwards. The stipulation that the data be accessable in all four compass directions is met by making the individual records directly accessable.

Before proceeding further, a name should be attached to these strings of elevations. A latitude contour defines such an array where the data points represent elevations along a constant latitude. A longitude contour is defined analogously. In instances where the orientation of the contour is irrelevant, they will be referred to as lat/long contours or simply contours. The line adjoining any two adjacent elevations in a contour is called a contour line segment.

Placing aside the concept of terrain masking for the moment, the steps involved in drawing the terrain scene are as outlined below.

Step 1: Determine which data file to use and which direction that file is to be accessed. For instance if the aircraft is heading westward (225 to 315 degrees), access records in the LONGITUDES file in decreasing order.

Step 2: Identify the beginning contours. In general, take the latitude and longitude of the aircraft and select the first contour encountered in the viewing direction. However if the aircraft is in a climbing attitude, the first few contours may in fact lie behind the aircraft. In this nose-up state then, the latitude and longitude where the aircraft's nadir vector intersects the sea-level plane is the position where the selection of contours begins.

Step 3: For each lat/long contour to be displayed, determine which portion of the contour will lie within the pre-specified viewing window. Apply formulae (B1) and (B2) to determine the projected position of each elevation point within the visible region of the contour. Then at each grid position an "L" shape is drawn. One edge of the "L" joins adjacent points in the current contour and the second joins the current grid position to the corresponding position in the previous contour The result is a "checkerboard" pattern as illustrated in Figure 2 in the main text of the paper.

Terrain masking is imposed within the structure outlined above. Each time a draw is to be executed, the visibility of the contour points at each end of that line segment will determine whether all, none or part of the segment will be drawn. Point visibility is a function of the height of the terrain lying between the viewpoint and the point in question.

Figure B1 illustrates the technique used to determine terrain masking. The x dimension of the viewing window is overlaid with an even grid (independent of the terrain grid). The y value at each of the grid points represents the highest (most positive value of y) projected elevation, at that x position, of the terrain contours already processed. The contours are processed outwardly from the viewpoint, so this array, which shall be called the "high-water-mark" vector E, correctly approximates the intervening ground. The quality of the approximation improves with the fineness of the x-dimension grid (the length of vector E). Linear interpolation between the grid points produces the "high-water-mark" (HWM) contour for ascertaining visibility.

In the majority of cases, contour line segements either will be completely visible or completely masked. In these cases it is desirable to have the algorithm carry as little "overhead" as possible. All that is required is an array interpolation and a comparison to determine whether the projection of a given elevation point is visible. As long as both end points of the contour line segments are of the same visibility (i.e. visible or masked) than a straight draw or move (respectively) is executed.

Special, more intricate software is executed only for the relatively infrequent cases where the current lat/long contour is passing behind or emerging from the intervening terrain. Under these circumstances the program searches for the intersection point of the contour line segment with the HWM contour. The visible fraction of the contour line segment then can be identified and drawn, followed by a move to the correct finishing position.

The terrain masking algorithm is constructed so as to search out at most one intersection between a given contour line segment and the HWM contour. For instance, if both ends of a segment are visible, then the whole segment is deemed visible and is drawn in its entirety. It could happen, however, that a portion in the middle of a segment is masked but both ends remain visible. The likelihood of encountering of this type of anomaly was not considered large enough to bother burdening the algorithm to accomodate it, and the realism of the total terrain image is virtually unaffected by this assumption.

After each lat/long contour has been processed, the high-water-mark contour is updated. The visibility array is maintained. As the next contour is processed it provides an historical account of what transpired on the "previous" contour.

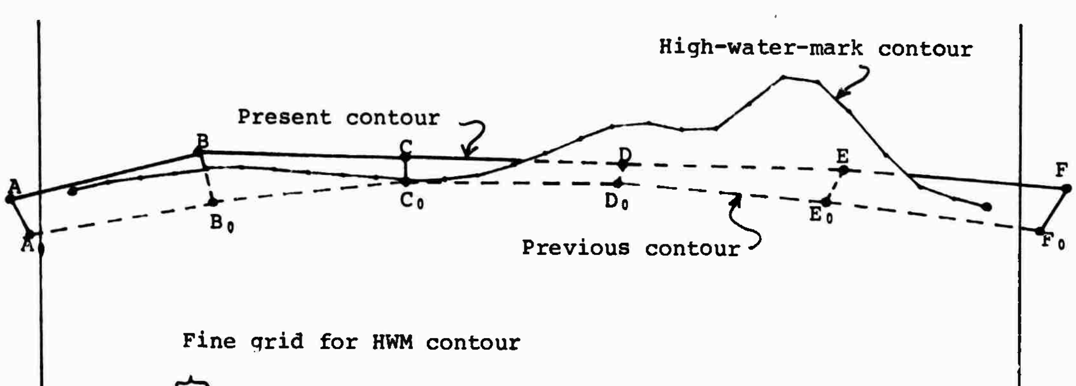

FIGURE B1

TERRAIN MASKING ALGORITHM

DISCUSSION

T.E.Spink, US

In Figure 6 you show angle above the terrain. Is that the angle between horizontal and the aircraft as seen by the target?

Author's Reply

The angle above terrain is defined as the angle between the aircraft and the highest point on the terrain between the two positions, as viewed from the defensive position. Paragraph 7, page 27-7, describes the parameter in detail.

F.W.Broecker, Ge

(1) How do you store the terrain contour? Or do you use a sensor to know the contour?

(2) How do you correlate terrain contour and height position of the aircraft?

Author's Reply

(1) The terrain information is stored on flexible discs in strings of either constant latitude or longitude. No automatic sensing of the ground below the aircraft position is assumed.

(2) The graphics imagery (Fig. 2 of papers) is produced as a feed back loop for the profile construction. The constructor also has a digital readout of aircraft height above terrain. Using these two aids, the constructor can assess if the aircraft's current position, with respect to the terrain, is realistic. This is analogous to how a pilot would accomplish the task under VFR conditions.

G.Hunt, UK

What constraints have you applied to the aircraft dynamics in the vertical plane?

Author's Reply

The aircraft accelerations in the vertical plane are constrained by g-limits, positive or negative, specified by the user.

R.Westley, Ca

When considering ground view from the cockpit, is it possible to include

(1) restrictions imposed by downward view cut-off by cockpit frame;

(2) restrictions of low atmospheric visibility?

Author's Reply

(1) Yes, with little difficulty.

(2) Complete darkness or "white-out" can be simulated by not employing the graphics imagery at all during the construction process. Partial restrictions could not be simulated. However, such realism is not required to meet the GAPS II objective, which is to be able to efficiently and accurately manouvre a simulated aircraft in a realistic manner over terrain.

COLOR DISPLAY TECHNOLOGY IN ADVANCED FIGHTER COCKPITS

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SUMMARY

Over the past four years, the use of color-display technology in military aircraft has received a significant amount of attention; to date, the question of how to use color effectively has not been answered. With high-quality color cathode ray tubes (CRTs) now being manufactured in the United States, Japan, France, and England, additional questions concerning the display performance requirements need to be answered prior to their introduction into the fighter cockpit. Weapon systems of today and those planned for the near term demand more effort from the pilot. A judicious application of color displays is considered to be one of the prerequisites to overcome this additional workload. This paper discusses the selection process being applied to available color display technology, the flight simulator evaluations and some of the uses of color displays. As a result of simulator evaluations, future work will be directed toward optimizing color CRT technology and the use of color displays in the cockpit of advanced fighter/attack aircraft.

INTRODUCTION

The latest technology developments in color cockpit displays contribute to meeting the performance requirements of today's complex tactical missions. The development of high-brightness color CRTs will allow their application in the high-ambient-light environment of the bubble canopy cockpit of which the F-16 is a prime example.

With information and color display data available from hardware manufacturers and recent investigations, an evaluation and demonstration program was established. The objective was to apply the flexibility of color to aid in reducing the workload of the pilot through the presentation of color-coded-pictorial status information in aircraft systems. One example of this is a pictorial status display for a stores management system (SMS). Unlike most SMS display formats of aircraft outlines, which use overlaid text that describes the type of weapons, this pictorial SMS has taken full advantage of graphic representations of external stores color coding to present weapons mode and status information. This method offers the pilot the opportunity to take a "quick look" at his stores status information without reading a large amount of text.

The results of the evaluation and demonstration program were then applied to the effort necessary to prepare a Prime Item Development Specification for color display equipment. This specification will contain the principle guidelines for soliciting hardware procurement of actual display equipment. Figure 1 illustrates a color enhanced cockpit.

KEY PERFORMANCE FACTORS OF COLOR DISPLAYS

Basically, there are two color CRT technologies available today: the beam penetration tubes and the shadow-mask tubes. The beam penetration tube, which has seen limited use in aircraft, is similar in construction to a monochromatic CRT with a single electron gun. It offers high resolution, has high-output efficiency, and meets vibration requirements of military aircraft with the same shock mounting as monochromatic CRTs. The tube phosphor is arranged in three layers on the screen. Layers are comprised of a red phosphor layer, a barrier layer that is intended to slow the electrons passing through it, and a green phosphor layer. Red is generated by setting the accelerating voltage relatively low, then the electrons are fully absorbed in the red phosphor. When the accelerating voltage is raised to a much higher level, the electrons penetrate both the red phosphor and the barrier layer and are absorbed in the green phosphor, which provides green emission. Yellow and orange are obtained at intermediate voltages or are produced by time sharing between red and green emission.

The most common color CRTs are the shadow-mask type similar to those currently used in most domestic television displays. Two means are available by which phosphors are placed on the CRT screen. These are the triad dot method in which three phosphors (red, green and blue) are deposited in a dot matrix format on the screen in front of a metal mask that has a round hole for each triad dot set; and the stripe method in which stripes (red, green and blue) are deposited on the CRT screen in front of a metal mask containing a slit opening for each set of stripes. Both types of shadow-mask tubes use a three-electron gun system to stimulate the peculiar phosphor type (red, green or blue). The shadow-mask (metal mask) provides the means by which the electron guns can be focused on one or any combination of the phosphor types. The phosphor colors (red, green and blue), when plotted on the CIE 1976 UCS diagram, produce the three points of a triangle necessary to generate any color available. Although the shadow-mask tube has a low output efficiency

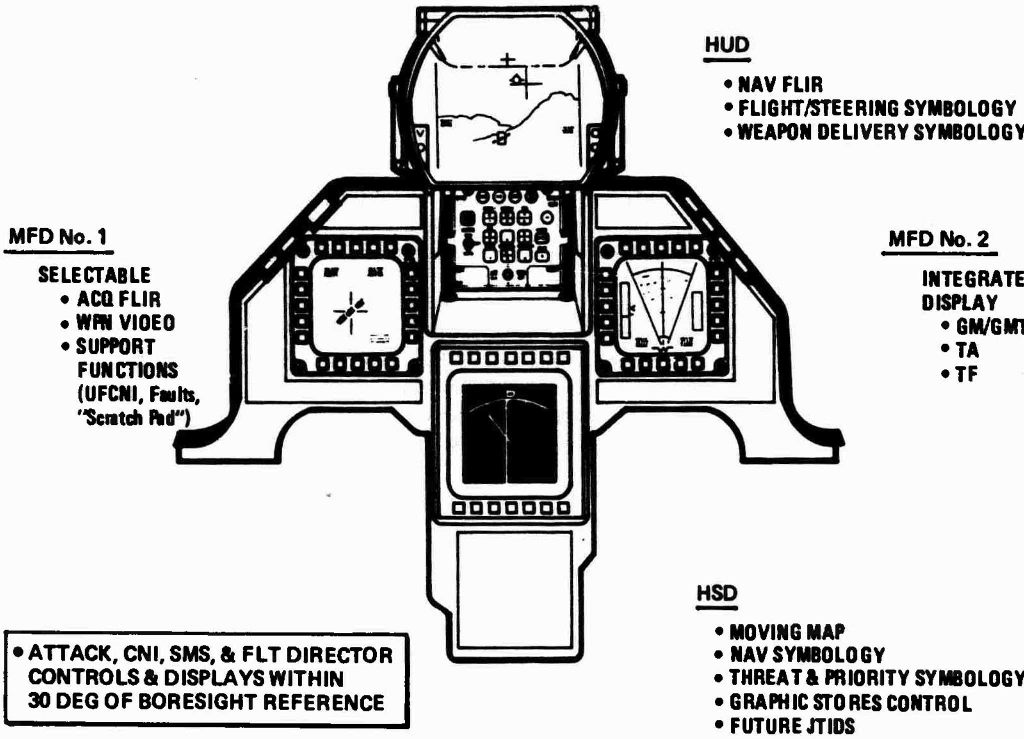

Figure 1 Color Enhanced Cockpit

and is subject to vibration problems, it has a distinct advantage over the beam penetration tube because of its multicolor output capacity.

Two techniques are available for presenting information on the display screen: the raster scan method and the stroke method. The raster technique, the most commonly used method today, is used in television receivers, video monitors, and computer terminals. Raster information is presented on the display by scanning the display face from left to right (horizontal lines) with an electron beam. As the besm travels across the screen it is modulated or pulsed to present information or data on that particular line. When the electron beam reaches the far-right side of the display a retrace pulse is received which returns the electron beam to the left side of display screen and, also, increments the electron beam downward one scan line. This continues until the bottom of the display screen is reached at which time a vertical retrace pulse is received that returns the electron beam to the upper left corner of the display where the process starts over again. This method of presenting information on the display allows for unprocessed video to be displayed (i.e., radar or camera video). Although they carry no information, vertical raster lines are generally used to define the resolution quality of the display. Airborne displays are normally 525, 625, or 875 line video which refers to the vertical resolution or vertical raster lines.

Stroke information is presented much like a draftsman making a drawing. The electron beam, with beam current off, is positioned from point X_0, Y_0 to X_1, Y_1, and no line is drawn. By energizing the beam current, a line can be drawn by moving the electron beam from point X_1, Y_1 to X_2, Y_2. By varying the beam current and the writing speed, the brightness of the display can be controlled. This makes the generation of displayed information more efficient. The disadvantage of the stroke-type display is that unprocessed video cannot be presented on these displays.

Both the raster and stroke display techniques have desirable qualities for airborne applications. With a combination of the two techniques, a stroke/raster or hybrid presentation can be obtained to take advantage of the two displays. Listed below are the advantages and disadvantages that can be experienced with a shadow-mask tube with raster, stroke, and hybrid display presentations.

RASTER

- o Advantages
  - oo Unprocessed video displayed
  - oo Symbology injected on a priority basis
  - oo Symbology recorded with a standard TV video recorder
  - oo Symbology highlighting techniques available (i.e., inverse video occlusion zones) for symbology
  - oo Flyback raster scanning consumes less power
  - oo Injected symbology requires no additional deflection power
  - oo Standard IC chips available for character injection
- o Disadvantages
  - oo Symbology distorts or takes on a stepped appearance when rotated
  - oo Symbol brightness limited to maximum TV brightness
  - oo Moire effects (fishtailing of horizontal lines) of raster and shadow-mask must be considered

STROKE

- o Advantages
  - oo Symbols are sharp, distinct and bright
  - oo Symbology easily interpreted even when rotated
  - oo Brightness range is wider
  - oo Programming comprehensive, high-resolution displays provide simpler hardware than complex raster displays
  - oo LSI chips available for stroke symbol generator
- o Disadvantages
  - oo Deflection power for random nature of stroke writing technique is larger
  - oo Unprocessed video cannot be displayed
  - oo Recording on standard TV video recorder cannot be obtained

HYBRID

- o Advantages
  - oo Unprocessed video displayed
  - oo Stroke symbols are sharp, distinct and bright
  - oo Static fixed raster symbols can be highlighted
  - oo LSI chips available for stroke symbol generator
  - oo Recording capability for major portion of display picture is provided
- o Disadvantages
  - oo Deflection power for random nature of stroke writing technique is larger
  - oo Vertical retrace time limits amount of stroke symbology

Given these considerations, hybrid color displays appear to be the best-suited to the next generation of fighter airplane cockpits. This is not to say that other types of color displays could not be used in cockpits under restricted conditions. There is some question if color raster symbology is acceptable under high-ambient-lighting conditions. Although stroke displays offer the advantage of being viewable under high-ambient-lighting conditions, they lack the ability to display raster video.

GENERAL APPROACH TO NEW TECHNOLOGY ASSESSMENT

A five-phase program was defined to demonstrate color display technology in a cost-effective manner. These steps were industry surveys, laboratory testing, pre-simulation evaluation, simulation and flight demonstration. With this incrementally-phased "building block" approach, the funding profile for the program was controlled in a way that permitted the exploration of numerous technologies at the same time within limited budget constraints. The key to making this possible was to hold down the front-end cost of the development cycle and to specify the equipment around the requirements established through pilot feedback.

In the design and integration of a color display system into military aircraft, the display engineers and human factors engineers have separate but overlapping responsibilities with a common goal - the development and utilization of flyable hardware. It was the responsibility of the human factors engineers to develop the utilization concepts for the system and to define the general display-related requirements based on the operational environment of the system. The responsibility of the display engineer was to keep the human factors engineers informed of equipment and technology limitations, and to provide hardware designs that meet the overall requirements. With engineering responsibilities defined, efforts were then directed to the ultimate goal of flight demonstration of a color display system.

The first phase of the color display program was an industry survey to determine what equipment and what performance data were available from vendors. The data obtained were used to determine what equipment would be required and best suited for laboratory testing and pre-simulation validation. Although the performance of the color display was important for these two phases, it was not the driving factor. Of more importance was the symbol generator, to be interfaced with the color display, which would have to be programmed without expensive interface equipment.

The purpose of the laboratory testing is to obtain the information necessary for generating specifications. The specifications for color displays need to be responsive to the operational requirements. Before specifications can be defined for airborne color displays, the effects of extreme lighting conditions on color display performance and specific color selection under these lighting conditions must be examined. To accomplish this, the color display is coupled to an integrating light sphere with a variable lighting source. This allows for variable, uniform illumination within the sphere and on the display face on which light output measurements will be made with a spectrometer. In addition, this information, coupled with human performance guidelines associated with color displays, is used as a guide to select a set of colors that is acceptable under all ambient lighting conditions. This includes selecting minimum brightness levels for night viewing, which is sometimes overlooked because of the effort that is expended to "beat the sun" at high-ambient conditions.

The pre-simulation evaluation uses a test-bed approach to evaluate display formats. This approach allows new cockpit display concepts to be quickly examined at low cost as compared to the time and money required to support a total cockpit simulation effort. The technique ranges from the use of single display setting on laboratory work benches for a quick "first-look" at the display concepts, to simple integrated cockpit mockups outfitted only with active devices necessary for the evaluation. In this manner, test-bed evaluation provides proof-of-concept testing of the color display formats prior to commitment to full simulation.

The basic tool in demonstrating color display concepts has been the F-16 Advance Cockpit Simulator. To obtain exposure for the color display concepts, a three-phase program was developed with the F-16 Advanced Cockpit as the test-bed. The three phases are described as follows:

Phase I - This was a low-cost demonstration in which video tapes were used to illustrate a map display, and static flight and engine instruments (provided by a symbol generator) were presented on a five-by-five-inch color display (stroke/raster). In order to make the simulation somewhat realistic, the color moving-map video tapes were manually synchronized with dynamic head-up display video. Static flight path information was then displayed over the color-moving-map video to demonstrate the flexibility of the color display system.

Phase II - Phase II provided for a full-up color-moving-map reader and a color display system that included a dynamic symbol generator and a five-by-five-inch color display (stroke/raster). This configuration was interfaced with the simulator computer for a full-up simulation effort. The Phase II configuration allowed for the presentation of dynamic flight information overlayed on the map, dynamic threat information presented on the color display, and the option of displaying color or monochromatic map video.

Phase III - The hardware configuration of Phase III was the same as that of Phase II with the addition of extensive software. The additional software provided the dynamic electronic flight instruments and a dynamic pictorial Stores Management System (SMS). This configuration demonstrated the full flexibility of color in the fighter aircraft cockpit.

The final step in this program is the flight demonstration of hardware and the display concepts. Efforts are now underway to obtain flyable hardware for this demonstration. The hardware configuration and concepts for the flight demonstration will have evolved out of the laboratory testing, pre-simulation validation, and simulation efforts at General Dynamics.

SPECIFICATION DEFINITION

Specification definition for color displays takes on a totally different character than that previously considered for monochromatic displays. This is primarily due to the human performance characteristics associated with color perception. Therefore, new design areas, e.g., color sensitivity due to ambient light, must be addressed.

Typical monochromatic display specification requirements, such as contrast ratio, maximum brightness and resolution, have now been replaced with discrimination index, chromaticity/color difference, color luminence, and beam size. One has to be very cautious when determining the soecification values for the new requirements and must not force the previously achieved monochromatic values into the color specification; each requirement needs to be addressed on its own merits. Other standard requirements for displays, such as, linearity, focus, sizing stability, CRT life, jitter, and distortion, are applicable to both color and monochromatic displays, and are therefore easily transferred to a color specification.

Four factors have to be considered in determining the specification requirements: (1) human factors requirements, (2) hardware displays definition, (3) pilot/vehicle interface and information presentation requirements, and (4) cost of hardware. Figure 2 illustrates specification information flow. With these factors in mind and with the aid of theoretical evaluations and information, the basic specifications were assembled. The use of additional information obtained by the demonstrations conducted during this study with available color display hardware resulted in refinements to the specification requirements. The development of a final color specification has yet to occur. The process will be an iterative one based largely on lessons learned in early engineering and display development activities, such as the one described in this paper.

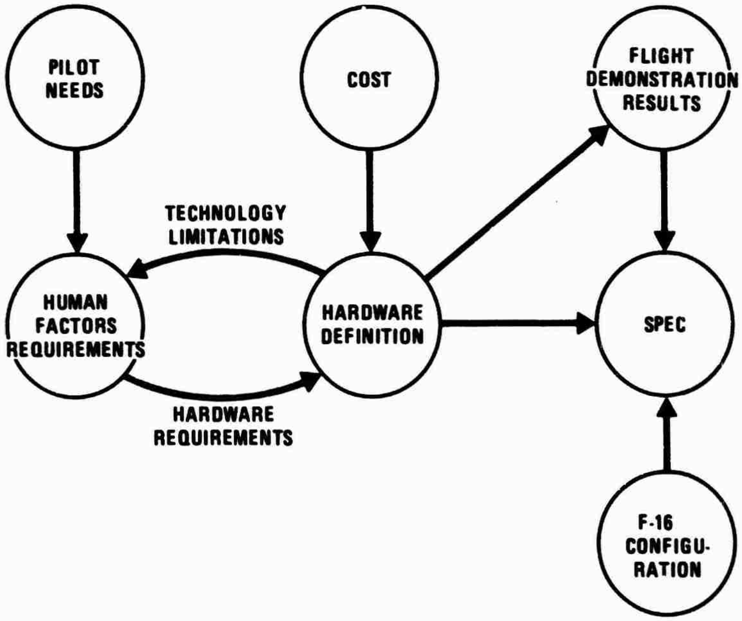

Figure 2 Information Flow for Specification

COLOR DISPLAY CONCEPTS - PICTORIAL STORES MANAGEMENT

The increased severity of the threat environment that modern weapon systems must survive has driven air-to-ground fighters to very low altitude, which, combined with modern weapon technology, has increased the information required in the cockpit. The increased information coupled with the trend toward smaller instrument panels has resulted in time-shared, multifunction displays. The necessity to time-share displays places a premium on the efficient presentation of information in terms of, not only what is displayed and when it's displayed, but how the specific information is formatted.

Pictorial displays can potentially ease the workload of the pilot by providing necessary information in a form that can be easily and quickly assimilated. Cockpit demands for time-sharing necessitate that displays be formatted as effectively as possible. The pilot should be able to acquire the desired information with a quick glance. Pictorial formats permit more efficient transfer and assimilation of large quantities of data quickly. Also, utilization of effective pictorial graphics can reduce the display of alphanumerics - a time-consuming method of transmitting information. The color dimension provides a natural coding of levels of urgency, as well as definition of homogeneous data sets on the display. By providing more cues for discriminating information, color can increase the flexibility of a display, thus allowing the display of more highly integrated information formats. The added color dimension may also reduce information acquisition time by reducing search time on a display. The added clarity and flexibility provided by the color dimension contributes to efficient acquisition of displayed information.

The pictorial representation of stores status information, using a color engineering graphics approach to stores symbology, proved to be universally favored in our initial evaluation when contrasted to existing alphanumeric displays of status information. The color-graphics approach to stores symbology provided easily discernible stores symbology with the exception of weapon model information, such as AGM-65B versus AGM-65D which has a similar or identical shape. A single model-designation letter has been proposed to handle this.

The pictorial stores display allows a distinction to be made between status information and system control information which typically shows up as alphanumeric labels adjacent to the bezel-mounted multifunction display switches. This separation of status and control information allows the pilot to effectively declutter his display of information currently not in use. The declutter (DCLT) switch is mechanized to eliminate all system control labels and leave only pictorial status information. The ability to declutter displays is a significant benefit of the pictorial Stores Management Set display format.

The operational sequencing of the stores status display relies on the color-coding of existing symbols to transmit information on the mode of operation (F-16 Master Modes) and weapon sequencing. For example, when the pilot checks the stores management system before engine start to determine that the proper number, type, and arrangement of weapons is loaded in the stores management system, the status display is green. The color green was selected because it is the most frequently observed color in the electronic cockpit (P-43 green phosphor is a common display phosphor for monochromatic displays). The remaining colors are used for high-information content displays. As the display is sequenced by the master operation mode (air-to-ground, air-to-air, dogfight, gun) of the aircraft, the color yellow is used to transmit to the pilot the stores/weapons available for use in the current operating mode. This display presents the pilot with information as to which subset of his hands-on control functions are available, i.e., will a missile or a bomb go when the "bomb release" button is depressed.

Figure 3 provides an illustration of the weapon station selection, weapon arming, release, and hung weapon indications in the air-to-ground mode. The color red in combination with specific graphic configurations is used in these cases. An example of a tactical sequence will aid in clarifying the display indications. As the aircraft moves into the attack phase of operations, the pilot selects the numbers and type of weapon to be delivered, the stores system selects the proper set of weapons stations and electrically actuates the weapons station; the weapons stations are now armed and any fire pulse transmitted by the system will result in a weapon release. As the attack is pressed, the selected weapons are armed; this is depicted by coloring in solid the mid-50% of the weapon symbol. In addition, nose/tail fuzing information takes the same form, i.e., nose-fuzed weapons are depicted by a solid color in the forward 25%. The depiction of a released weapon is its disappearance from the display; the representation of a hung weapon is a cyclic flashing of the red weapon symbol at the appropriate weapon station.

Figure 4 illustrates the air-to-air configuration for the stores display. The symbolically represented information and the color coding is similar to the air-to-ground display with two exceptions. The first exception depicted is the use of blue in the head of an IR missile to indicate that the head is being cooled. The second applies to all off-boresight weapons. The ray emanating from the missile head gives the pilot an indication of where the seeker-head has locked on a target. This could potentially minimize the expenditure of weapons on the same target in a multi-target engagement.

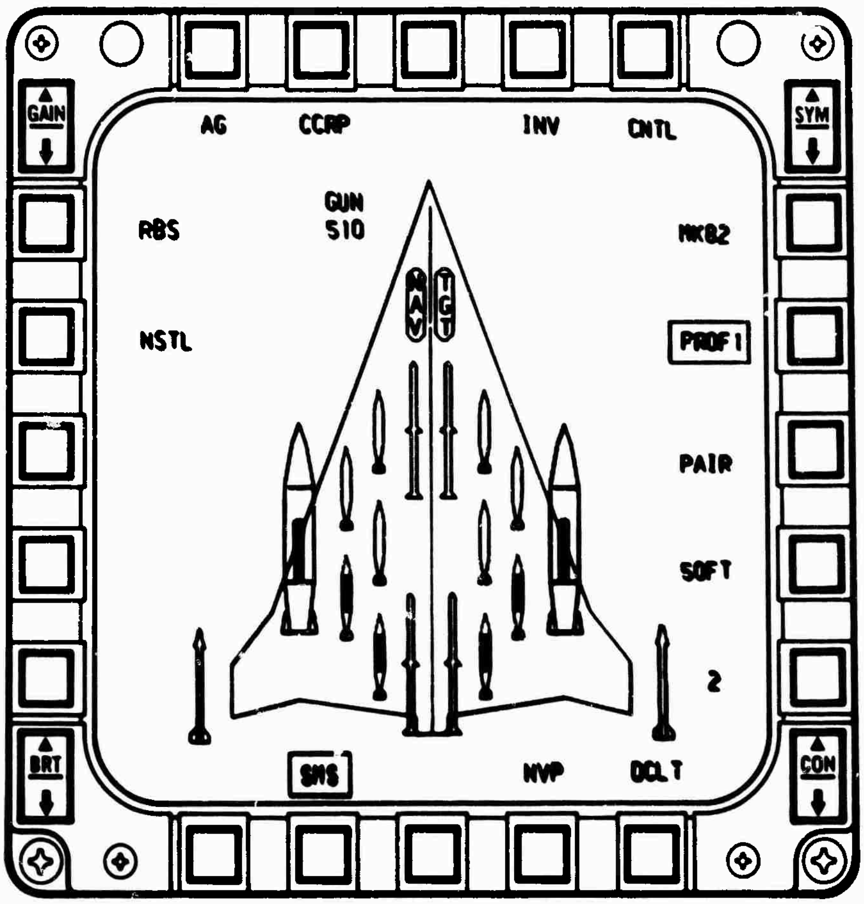

Figure 3 Air-To-Ground Weapons Configuration

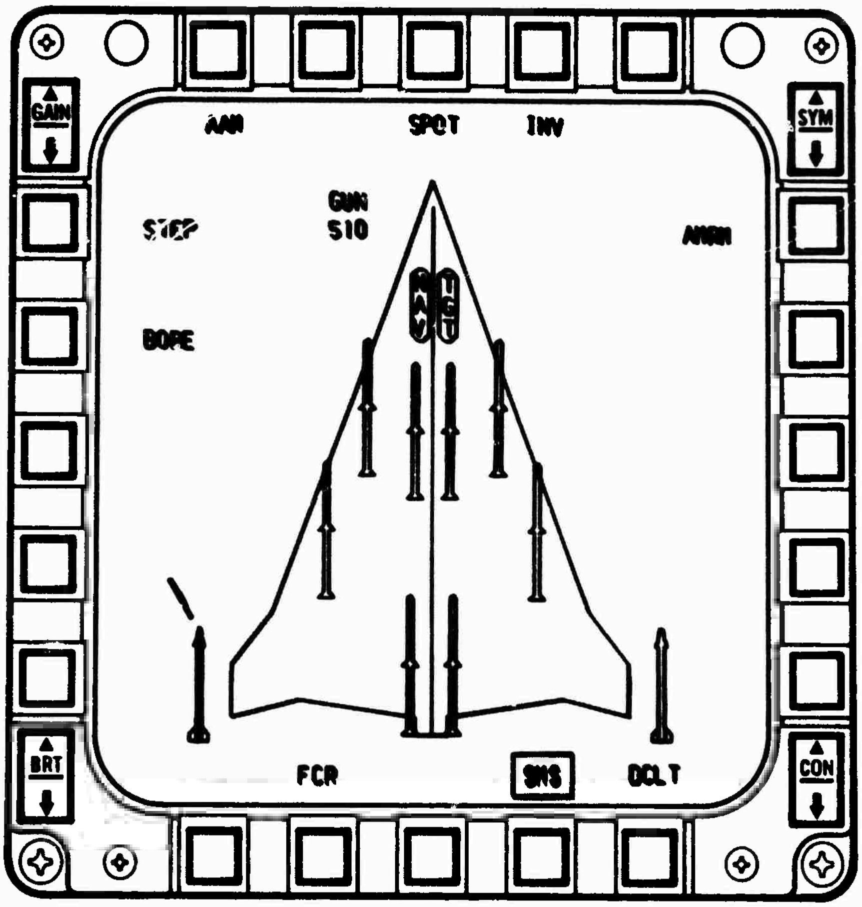

Figure 4 Air-To-Air Weapons Configuration

CONCLUSIONS AND OVERVIEW

The general approach used to develop and evaluate the application of color in the near-term advanced fighter cockpit have been described. In addition, a technical baseline has been established for directing future work that will lead to the utilization of color displays in next-generation aircraft. With expanded technical assessments of the use of color in the specific operational environments, it will be possible to develop the correct balance between actual performance requirements and costly, unwarranted requirements.

Too often, the performance requirements for a new technology are over-specified when there is any uncertainty with respect to the real requirement. The emphasis should be on the user's actual requirements and the systems designed to meet those requirements. The ultimate goal should be to provide the pilot with a more effective, economical way to accomplish the mission. We must be able to afford color to meet anticipated complex weapons and mission requirements of tomorrow's fighter/attack aircraft. It will require a cooperative effort between the user, the aircraft systems integrator, and the display manufacturer to develop and integrate the right system.

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DISCUSSION

C.Maureau, Fr

Précédemment les instruments électromécaniques étaient dispersés sur les planches de bord. Dans les solutions plus récentes utilisant des tubes cathodiques monochromes, les informations sont regroupées sur des écrans occupant une surface également importante. De même que les instruments anciens restaient là souvent sans être vraiment regardés, les écrans multiples sont souvent inutiles et risquent même de distraire l'attention du pilote de directions extérieures où elle serait plus utile – il restera donc là probablement très souvent éteints. L'expérience du Mirage 2000, par opposition à celle d'avions portant – comme le F-18 – plusieurs écrans juxtaposés, montre que l'introduction de la couleur offre un moyen de diminuer la distribution spatiale de l'information en poussant en quelque sorte plus loin l'intégration de sa présentation. Envisagez-vous en corrélation avec l'introduction de la couleur une diminution du nombre des visualisations tête basse?

Author's Reply

The displays are always presenting a picture except when a video missile is disconnected. The mission requires that all the available data be presented such that the pilot can quickly observe his situation without having to select each prime mode (i.e. radar, stores management).

R.A.C.Smith, UK

The paper refers to conducting laboratory tests on colour displays in high ambient lighting conditions. My question was as follows:- was the high ambient lighting used representative of sunlight in the spectral sense, since the perception of colour must surely be affected by the "type" of ambient illumination?

Author's Reply

Yes. We use the Hoffman integrating sphere that contains high intensity halogen lamps that give off energy that simulate the spectral characteristics of the sun.

K.F.Boecking, Ge

(1) You did not mention the beam-index-system when presenting different colour-display-systems. What is the reason?

(2) When combining stroke and raster information in the project map display with symbology surrounding do you need 4 guns?

Author's Reply

(1) The trend in the colour tube industry is to develop the shadow mask to the full MIL STD and no prime display supplier appears to be too interested in the beam index type because it is not cost effective.

(2) An additional gun is not needed and the existing three guns are used to write the stroke information during vertical retrace time.

R.Davies, Ca

The modern business jet pilot takes colour display of weather radar for granted and many have colour engine instrument displays. Some business jets already have EFIs with colour radar display on the HSIs. Now the question: The putting of colour CRTs into a fighter ground attack aircraft which is committed to flying into combat zones, with the distinct possibility of receiving "foreign objects" in the cockpit from shellfire, shrapnel etc., seems to be very vulnerable to potential total display loss. What is General Dynamics' and the Air Force attitude to this?

Author's Reply

The basic trend for all combat fighter aircraft is to put more CRT displays (mono or colour) into the cockpit because of the multimode missions that have to be performed. With this, a swap or dual mode is available to allow these displays to serve as back-up for each other. These CRT displays are ruggedized to withstand the usual environment, but as you say cannot tolerate shellfire – neither can flight instruments. It is quite possible that the near term two-seat aircraft could have as many as seven CRTs onboard, with a suggested location of 3 at the front and 4 at the aft seat. This will be probably a balance of 2 mono, 1 colour in the front seat and 2 mono, 2 colour in the back seat.

CRITICAL FACTORS AND OPERATIONAL RESEARCH IN TACTICAL FIGHTER AVIONIC SYSTEM DEVELOPMENT

by

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SUMMARY

The problem to deaign and to develop a complex system is considered as a multiobjective optimization problem. In particular, the ca3e of the avionic system of a tactical fighter is illustrated; assumptions and objectives of the project are listed and discussed. It is deacribed an approach to the problem that uses Operations Research tools and techniques, Multiobjectives and Marginal Substitution Rate functions. A brief explanation of the method applied to the case of the design and development of a tactical fighter avionic aystem is done. It is pointed out that the approach allows to take into account not only the expected characteristics, but also the impact of implanned events on the system development.

Possible critical factors in the development process are emphasized by means of the computation of the Marginal Substitution Rates. A detailed example is given in respect to the Operational Mission Software development for the avionic system, with attention to critical factors individuation.

1. INTRODUCTION

Design and development of an airborne weapon system is supported by a multiobjective decision process. At every stage of the design and during development there are people who have in charge to select an approach or another, to choose an equipment or another, to take proper action against implanned events and so on. The decisions made by those people, or the reccomendation they give to a "decision maker", has an impact on the overall characteristics of the weapon system (objectives to be reached), like cost, effectiveness, maintainability, and therefore the "best" alternative must be selected. Because of the complexity of the problem and number of factors having influence on the final result, the "best" decision is to select the "best" compromiae among contrasting alternatives.

The Operations Research can assist the "decision maker" in his task by providing him quantitative indications about the characteristics of the system, trade-off indications and trends, resulting by selecting different alternatives.
The Operational Research tools and techniques are of general use for system of every level of complexity and project phase, e.g. full weapon aystem, aircraft, weapons; airframe, general and avionics systems; feasibility study, definition, development, service; new system, updating.
Different are the type of indicators that can be derived, the work to be made to compute them (computer simulation, flight test, ground test), and the "confidence level" related to the indicators and therefore the range of decisions they can support.
For example, during feasibility study of a weapon system, only preliminary information about new weapons may be available and very rough computer models, to determine its performance, can be made, but the decision is simple: feasible or not. Later on during deaign and development, better information results in a larger set of indicatora used to define detailed characteristics of the system.
The type of aystem under evaluation may vary the used indicators and the way in which they are computed from the available informations (e.g. atrategic weapon syatem and tactical weapon system are evaluated by means of different parameters, a full weapon system and an internal data transmission system may assign different weight to the same performance indicator).
The use of the Operations Research can be planned to extend in two directions during the life-cycle of the project: a top-down approach and a stepwise refinement.
Top-down approach means that the indicators are utilized in decisions involving simpler and simpler aystem components and parts, (from system, to sub-system, parts and components), when necessary information become available; stepwise refinement means that the same indicators, during project evolution, are effected by lower and lower uncertainty.

In particular this paper describes the Operationa Research approach for design and development of the avionic syatem for a new tactical fighter weapon system.An example of the aame approach applied to an avionic system component (Operational Software) is also given.

2. ASSUMPTIONS AND OBJECTIVES

The assumptions and the objectives of the project must be established.

2.1. The assumptions for the design and development of the avionic system for a new tactical fighter are related mainly to the aircraft characteristics and its role. As result of an higher level decision a certain amount of resources, depending on the aircraft physical characteristics, are allocated to the avionic system, that is :

- maximum installed weight
- total available internal space (and its partioning)
- electrical power available and characteristics
- internal environmental characteristics (e.g. temperature, vibration, EMP)
- air mass flow and pressure drop available for the cooling of electronic equipment
- physical interface with other aircraft systems

The above assumptions probably do not significantly change, or do not change at all, during the life cycle of the system.

The aircraft role has an inpact on the overall design and therefore on the avionic system, that is assumed to be affected mainly by:

- operational requirements related to the avionic system
- first line or demonstrator system
- time constraints
- single seat design
- handling qualities of the aircraft
- weapon inventory to be delivered
- figures of merit allocated to the avionic system (MTBF, MTTR, safety rate etc.)

Some of the above assumptions may vary significantly during the life cycle of the aircraft, particularly the weapon inventory.
Finally an important assumption regards the industrial resources available for the project, in terms of funds, manpower, facilities.

2.2. Minimal objectives of the design and development, not in order of priority, are :

- fulfilment of the assigned physical constraints
- fulfilment of the Operational Requirement
- achievement of the required figures of merit

Very important objective are also:

- fulfilment time contraints assigned to the programme
- not overcoming of ceiling cost
- achievement of a sufficient "growth capability"

The design and development activities must assure the achievement of the above objectives but, while several design and development strategies can certainly guarantee it, they differ for the level of fulfilment of the objectives.
In fact the objectives are intrinsically opposite; for example, better effectiveness (fulfilment of Operational Requirement) may be achieved with higher installed weight and electrical consumption, shorter development programme can be realized at higher costs.

Therefore project objectives are also the order of priority of the objectives and the parameter ratios (cost/effectiveness, time/cost) to be maximized/minimized.

These latter objectives depend strictly upon the overall program objectives and may very depending on the project requirement, in an updating programme the time constraints is more important than residual "growth capability" of the system, but cost/effectiveness is always to be minimized.

3. FUNCTIONAL DESIGN CONCEPT

3.1. Having established the assumptions and the objectives to be achieved by the design and development programme of the avionic system of the subject weapon system (tactical fighter) related to aircraft characteristics and role, other objectives, more related to the industrial practice, are to be fulfilled to prove the programme to be successful.

- A design at the state-of-the-art assures a reasonable life of the system (even if not so long as for the airframe) and permits to find most of the components on the market.
- The technical risk associated to the new technologies, at first time introduced by the industry in charge of the project, must be consistent with overall programme objectives (technological demonstrstor can suffer higher development risk than first line weapon system).
- Flexibility of the design allows easy implementation of required modifications, during system life cycle.
- Level of integration, redundancy, standardization must be carefully investigated in relationship with benefits, risk and state-of-the-art.
- System Architecture, mainly the computing and internal data transmission, is related to the above concepts and it is of capital importance to determine the potential evolution of the system.

3.2. It is assured, for the purpose of this paper, that the basic functional components of the project are the following:

- Integration means (internal data transmission system)
- Operational Software (Mission related software and computing devices)
- Autonomous navigation
- Assisted (by radio aids) navigation
- Weapon Aiming
- Store Management
- Electronic Counter and Survelliance Measures
- Communication and Identification
- Display and Controls
- Interface with other aircraft systems

During detailed design and development it is useful to have an indication of the level of fulfilment of project objectives in relationship with different implementation of the above functions. These indications provide quantization of the value of the alternatives but can also improve the understanding of system characteristics and dictate functional design improvements.

The tools and methods of the Operations Research can provide the means to compute the required indications to reach the "best" decision, that is the decision with the higher level of fulfilment of the contrasting design and development objectives.
In the following paragraph these tools and methods are briefly described, bearing in mind that they are not directly finalized to the design activity itself but the different design selection.

4. TOOLS AND METHODS

4.1. Being "α" an alternative of A, set of all alternatives to be considered, it is possible to associate to C (α), that is the action to choose α, a set of n numerical figures:

$$\gamma_1(\alpha),\ \gamma_2(\alpha),\ \cdots,\ \gamma_i(\alpha),\cdots,\ \gamma_n(\alpha) \qquad ; \qquad n \geq 3 \qquad (1)$$

which describes quantitatively all relevant information about C (α), giving an indication of the achievement of each project objective (i of n) by the action (Thierauf R., Klekamp R., 1975).

Each $\gamma_i(\alpha)$ can be determined by means of the Operational Research methods (mathematical simulation, test on models or on the real system, previous experience); when sufficient information is available, as in the case under examination, $\gamma_i(\alpha)$ can be expressed by a number.

It is moreover defined, for each objective (criterium of judgement of the action) a level of acceptability (a level not to overcome) L_i, i = 1, n, which corresponds to the requirement to which the action C (α) must comply.

Every considered alternative must therefore result in an action C (α) for which is :

$$L_i - \gamma_i(\alpha) \geqslant 0 \quad ; \qquad i = 1,n \tag{2}$$

This condition may seem not immediately applicable to some objectives, but it has the advantage to homogenize the numerical indication trends of objective fulfilment (also achievement of a minimum performance can be expressed in this way, for example MTBF, assuming that $\gamma_i(\alpha)$ is the difference between the minimum allowed value and the actual value, while L_i is zero).

When the n criteria (objectives) to be taken into account are numerous, it is not easy to compare the alternatives by looking only at the $\gamma_i(\alpha)$ and therefore it is useful to introduce an order of preference in A.

Among various proposed approach to solve the problem (Roy, B ... 1970) it has been showed to be convenient, for the level of definition and type of system under consideration, to gather the multiobjective functions γ_i into a unique function.
First step is to associate to each objective (function γ_i) a measurement of it, in arbitrary units, with relationship with a common dimension (the common dimension may be related to the resources required for objective accomplishment).
It means that the problem is deterministic and therefore it is possible to associate a value v_i to each objective, for each alternative α in A :

$$v_i\left[L_i - \gamma_i(\alpha)\right] \quad ; \quad i = 1,n \qquad \forall\, \alpha \in A \tag{3}$$

Function v_i is positive and non-linear.
The multiobjective function F is :

$$F = F(v_i) = F\left[v_i(\gamma_i)\right] \quad ; \quad i = 1,n \tag{4}$$

Among a number of function investigated, the simple additive function has been proven sufficiently satisfactory and convenient for the relation (4).
Therefore F can be a simple additive function :

$$F = \sum_{i=1}^{n} v_i\left[L_i - \gamma_i(\alpha)\right] \quad ; \quad \forall\, \alpha \in A \tag{5}$$

and, being :

$$v_i\left[L_i - \gamma_i(\alpha)\right] = p_i\, w_i\left[L_i - \gamma_i(\alpha)\right] \quad ; \quad i = 1,n \;\; \forall\, \alpha \in A \tag{6}$$

F becomes :

$$F = \sum_{i=1}^{n} p_i\, w_i\left[L_i - \gamma_i(\alpha)\right] \quad ; \quad \forall\, \alpha \in A \tag{7}$$

with the following conditions :

$$\sum_{i=1}^{n} p_i = 1 \quad , \tag{8}$$

$$0 \leqslant w_i\left[L_i - \gamma_i(\alpha)\right] \leqslant 1 \quad ; \quad i = 1,n \quad \forall\, \alpha \in A \tag{9}$$

Function F can establish a complete ranking of preference in A.

4.2. Nevertheless F does not solve completely our problem because, while it gives information about the best alternative, it does not indicate how the selected alternative is sensitive to the variation of the condition that determined its selection and how the achievement of various objectives is interrelated.

To explain, it may be that the "best" alternative has an effectiveness strictly dependent on available industrial facilities and system integration level while the "second" one does not have a such sensitivity and, for this reason, should be preferred.

The function that can give indication about the above characteristics of the choice is the "marginal substitution rate"(MSR) between the i-objective and a fixed criterium of reference, that is the numerical value of the i-objective function of the variation of the term of reference.
The denomination "marginal" points out that the value of the function MSR, for every value of the term of reference, depends upon values of all objectives in that point.
The criterium of reference may also be another objective, in this case the Marginal Substitution Rate gives the relationship (in arbitrary value units) between the two objectives.

Being ϑ the variable associated to the term of reference, the Marginal Substitution Rates appears as showed in figure 1 as function of ϑ, of which $\alpha(\vartheta)$ is theconsidered implementation.
Computation of MSR's is very difficult because it requires large amount of information (including practical knowledge of people who experienced similar situations) and great effort to reduce the information to the illustrated format.

If the MSR's are computed for each α in A and for all relevant criteria of reference, it is possibile to compute a multidimensional function F*, on which the non linear programming techniques can be applied to determine the best values of each ϑ (Mangasarian O., ..., 1969).
The complexity of the problem under consideration do not allow usually to obtain a complete numerical expression of the function F*; nevertheless the computation of MSR's for the most relevant objectives and terms of reference, and their comparison by means of a common measurement (function value, eqt. 3), can be very effective to show important characteristics of different alternatives.
Computation of MSR's between objectives has also great usefulness in determining the coefficients ρ_i in equation (6).

Application of the above described tool to a problem is simple, but its effectiveness depends greatly upon the level of confidence of the input information. To improve the confidence level it is very useful an "hystorical" data base, containing the "hystory" of the objective measurements during the evolution of the project; appropriate filtering algorithm applied to the data base improves the accuracy of measurements.

Experimental implementation of this tool with the related data base is currently in progress on a digital computer.

5. THE AVIONIC SYSTEM OF A TACTICAL FIGHTER

5.1. The assumptions, objectives and design concepts outlined in para. 2 and 3 can be referred to many system and in particular to the design and development of the avionic system of a new tactical fighter. In this and the following paragraph, a simplified approach to the problem to choose among various system design solutions, is summarized,also in order to explain the use of the tools and methods described in para 4.

In spite of the limited effort and limited amount of information, this example provides indications coherent with the results of more complex and time consuming analysis completed for similar systems.
To proceed in the analysis it is necessary, first of all, to specify the values of the various parameters assumed to be significant to determine the problem (see para 2).

- Physical characteristics are therefore assumed (maximum weight may be around 400 kg, air mass flow 30lb/min at 40°C, electrical power available 10 Kw and so on).
- Parameters related to aircraft role are indicated (it is assumed a first line weapon system ready for series production in 48 months from go-ahead), operational requirements (weapon delivery accuracy, vulnerability, survivability, maintenability), weapon inventory ("iron" bombs, A/G & A/A missiles) and so on.
- Industrial resources available for the project are also to be precisely specified, in term of funds, manpower, facilities.

5.2. Then objectives must be specified. The objectives listed in para 2. are self-explanatory and its numerical value can be determined as direct consequence of the assumptions. Also design concepts of para. 3. should be considered desirable objectives, but a clear specification in term of relevant design parameters in less straightforward.

- State-of-the-art of a design can be regarded as the percentage of the components (functional blocks) of the system that can be found, with minor modifications, on the market.
- Technical risk associated to new technologies is related to industrial resources to be allocated to assure a reasonable technical success probability to the development.
- Flexibility, level of integration, redundancy and standadization are closely dependent on system architecture and are defined by parameters such as the occupancy of the integration means, the memory storage and computing capability available in excess to the requirement; integration level, that is the percentage of information flow available for all system components; percentage of value of system devoted to shared functions (e.g. data transmission interfaces, controllers); flexibility,that is the percentage of value

be added to the shared functions to add a new capability to the system (e.g. cost of modification of the avionics to include a new weapon to the weapon inventory).

5.3. Now a functional design of the avionic system can be outlined and the numerical indicators (γ_1, γ_2, ..., γ_n) of objectives and acceptability levels (L_1, L_2, ..., L_n) can be computed.
For purpose of comparison three solutions, based upon the functional partitioning identified in para. 3.2., are considered.
First solution (called system type A) is based on a conventional point-to-point dedicated transmission system, a single central mission computer, a low level of integration, function implemented in digital/analog technology.

Design type B is based on a dual redundant time multiplexed data bus (MIL-STD-1553 B type), duplex central mission computer and partially distributed computing, high level of integration and digital implementation of system functions.

Design type C has a multiplexed data bus, fully distributed computing, very high level of integration (all functions fully integrated), all digital implementation of functions.
The considered objectives, their indicators of the above three systems are showed in table 1 (remember that L_i are levels not to be exceeded).

5.4. The multiobjective function F is now computed starting from parameters of table 1, by computing values ν i (see. eqt. 3) and coefficients p_i (eqt. 6), called weights; results are showed in table 2.

Values obtained for the multiobjective function indicate as less adeguate the system type A, while the slight difference between the preferred types (B and C) is well within the precision ϵ of the method, that in this case can be extimated to be ϵ = 0.050.
Others considerations are required to choose between B and C, these considerations are illustrated in the following paragraph.

6. CRITICAL FACTORS

The Marginal Substitution Rates (MSR, described in para. 4.2.) are computed for a more detailed investigation of avionic system type B and C (see para. 5).

6.1. Variations of assumptions result in MSR having an external term of reference. For example, available industrial resources variation induces corresponding MSR's of the most important parameters (remaining parameter are not affected or the MSR is not computable) that are shown in fig. 2 for system B and fig. 3 for system C.
The variation of the industrial resources, funds, manpower, facilities are expressed in conventional units of cost, being 250 the value assumed for the analysis of para. 5, while MSR's are expressed in unita of value; remember thst an higher value corresponds to a better situation (value of technical risk one means no risk).
Variation of multiobjective function F against the reference parameter ϑ variation, for the considered objective, is shown in table 3. It appears clearly that availability of industrial resources is a very critical factor for solution C.

6.2. The relationship between objectives is clearly shown by MSR that has as term of reference the value of an objective. These MSR's indicate the impact on the syatem when an objective does not fully schieve the design target.
It is considered an example of criterium of reference the integration level of the system, in fig. 4 (system type B) and fig. 5 (system type C) are showed the corresponding MSR's for system effectiveness (Operational Requirement fulfilment), cost and flexibility. All indicators are measured in units of value, remember that each MSR depends on all values of objectives and therefore to different systems of equal integration level value do not necessarly correspond on equal value of MSR.

Partial varistion of the multiobjective function F agsinst the referenced parameter variation is shown in table 4. Again system type B is less sensitive to the varistion than system C, for which the achievement of the desired integration level is a critical factor.

6.3. According to the indications given in thia paragraph and in para. 5, a deaign of type B can be considered leas criticsl to be implemented for its lower sensitivity to project conditions and therefore it ia preferred with assumed importance for development risk; nevertheless it is to be noted that deaign C can show better cost/effectiveneas ratio and this feature could induce to prefer type C if its importance increases.

7. OPERATIONAL SOFTWARE DEVELOPMENT :AN EXAMPLE

Among the functional componenta of the avionic syatem listed in para. 3.2, there is the Operational Software, the on-board Software directly related to aircraft mission (including data transmiasion software but not the equipment embedded software/firmware, like symbol generation Software in displays, signal elaboration in radar etc.).
In this paragraph the Operational Software Development Process will be examinated, utilizing the tools described in para. 4. and particularly the MSR's to find out the critical factors affecting it (system type B of para. 5. is assumed).

7.1. Assumptions.

- The Development process under examination starts from the finalization of the Specification of the Software (also called Operational Flight Program, OFP) and enda when the Software itself haa been verified and validated on the real airborne computer in isolation on ground (integration with the rest of the system is considered part of another procesa).
- The target computer for the software, that is the on-board computer of the avionic system, is a state-of-the-art equipment with aufficient computing capability (200 K Iatr/s, thousands of Wheatstone Instruction per second) and available memory (96 K byte).
- The available toola to support the development process are :
  a) a mainframe host computer with the following characteristics
     . available computing power 1,000 K Iatr/s (thousands of Wheatsone instructions per second)
     . central memory 1 M byte, available fast masa memory 300 M byte
     . 6 working stations (video terminals)
     . complete set of peripherals (line printer, magnetic tape drivers etc.)

  b) a test station for the airborne equipment program verification and performance evaluation.

  c) a complete set of programa to assist the programmers in preparation, debugging and validation of the Operational Software.
- The airborne equipment (misaion computer) and the support tools are mature and proven.
- An amount of 64 K byte of memory are foreseen for the Operational Software; programming in high order-language by six senior analysts and eighteen skilled programmers is scheduled in 24 months; exhaustive specification and assistance by four system engineera are available.
- Documentation of activity and program to be produced.

7.2. Objectives

- Production of the required Operational Software within the available time and fulfilment of the Specification.
- Minimization of cost and technical riak (defined aa the probability to exceed time constrainta).
- Not exceed a total loading of 75% for the hoat computer.
- Maximization of personnel (analysts and programmers) productivity.
- Maximization of program validation effectiveneaa.
- Not exceed a total time loading of 70% and a memory occupancy of 64 K byte for the airborne computer.

7.3. Objective fulfilment indicatora are then computed with extenaive use of Operations Research tools and previous experience (for example, a ratio of 70/30 between ahort and long computer instructions determines the number of inatructions in 64 kbyte of program, an average cost per inatruction of 100 $ permita cost calculation, an average programmer production of 100 instructions per month is assumed).

The results are summarized in table 5. For an immediate reault evaluation the indicators and acceptability levels do not exactly follow the definition of eqt. (2), but they can eaaily reduced to them.
Examination of table 5 gives a number of immediate indications of some critical aspecta of the process.

- Programming in high order language is assumed and it results evident that this ia essential for the development process. In fact a ratio in the range of 6:1 can be conaidered for the ratio between number of instructions programmed in high order and assembly language and therefore time constraints cannot be achieved with the available number of analysts and programmers. Increase available personnel does not solve the problem becauae it also increase the multiprogramming level and saturate the host computer (see for example, Bradbury D ..., 1978), increase cost, risk and decrease significantly the validation effectiveness.
- The low productivity (70%) indicates a poasible reduction of the number of analyats and programmers with low impact on the other objectives.

7.4. To find out critical factors of the development process a MSR analysis is performed.

- Variation in the maximum level of multiprogramming of the host computer. It is a synthesis of all computer characteristics (computing power, central and mass memory, operating system characteristics) and, for the purpose of table 5, it was assumed equal to six.
  This level can be increased or decreased assuming a different hardware implementation or variation of computer resources assigned to the software development activity.
  In figure 6 MSR's computed against multi programming level variation are shown, remember that MSR's are interdependent. Host computer resources, that has impact on the number of contemporary users, appears to be an high critical factor for Software Development process, particularly for fulfilment of time constraints.

- Finally figure 7 shows risk and productivity MSR's against airborne computer utilization. This objective does not have a critical factor to the above objectives achievement.
  In the same way all other factors can be examined and their impact on the software development process evaluated.

8. CONCLUSIONS

This paper illustrates An operational analysis tool to assist in understanding complex system features. ~~has been illustrated.~~
Application to the design and development of the avionic system of a tactical fighter ~~has been~~ is described, with special regard to critical factors affecting the system development or part of it.
It is pointed out that the described tool ~~does~~ not be used to design or develop the system, which requires much more complex activities, but it is a possible useful way to summarize and present the results of the Operations Research in order to trim the project in the right direction.
Additional effort toward system optimization, configuration definition and development trade-offs can be made by means of the Marginal Substitution Rate factors.

Application (Such as) of the above tools and techniques has been ~~done~~ and is currently (being) done for systems similar to the examples, ~~like~~ the development of the avionic system of AM-X aircraft, and for other military aircraft projects. The obtained results show the validity of the approach and encourages its application also in future projects.

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	Objective	L_i	System type		
			A	B	C
1.	Physical Char.	400	395	380	370
2.	Operat. Req.	0	-0.25	-0.5	-0.8
3.	Time Constr.	48	38	42	46
4.	Cost	1000	850	800	800
5.	State-of-the-art	1	1	0.9	0.7
6.	Techn. Risk	250	0	50	200
7.	Integr. Level	0	-20	-60	-100
8.	Growth. Cap.	50	30	30	20
9.	Flexibility	10	9	2	1

TABLE 1

System design indicators (γ_i) in arbitrary units for three different avionic system alternatives.

	Objective	P_i	System type		
			A	B	C
1.	Physical Char.	0.1	0.05	0.3	0.4
2.	Operat. Req.	0.1	0.25	0.5	0.8
3.	Time Constr.	0.1	0.5	0.3	0.05
4.	Cost	0.15	0.5	0.6	0.6
5.	State-of-the art	0.1	1	0.9	0.7
6.	Techn. Risk	0.1	1	0.8	0.2
7.	Integr. Level	0.1	0.2	0.6	1
8.	Growth. Cap.	0.1	0.4	0.4	0.6
9.	Flexibility	0.15	0.1	0.8	0.9
	Value of F		0.430	0.590	0.600

TABLE 2

Values, weights and multiobjective function for three different avionic system alternatives.

	Δ F	
$\Delta\vartheta$	type B	type C
-50	-0.023	-0.050
+50	+0.028	+0.040

TABLE 3

F partial variation assuming resources variation

	Δ F	
$\Delta\vartheta$	type B	Type C
-0.1	-0.023	-0.050
-0.2	-0.035	-0.100

TABLE 4

F partial variation assuming integration level variation

	Objective	γ_i	L_i	p_i	Value v_i
1.	Time Constr.	20	24	0.2	0.3
2.	Cost	2500	3000	0.15	0.2
3.	Tech. risk	5%	10%	0.1	0.5
4.	Product	70%	60%	0.1	0.25
5.	Val. Effect	80	50	0.2	0.6
6.	Airb. Comp. Utilization	0.65	0.7	0.1	0.2
7.	Host Comp. Utilization	0.60	0.75	0.15	0.7
	Multiobjective function F = 0.410				

TABLE 5

Multiobjective indicators for Software Development Process

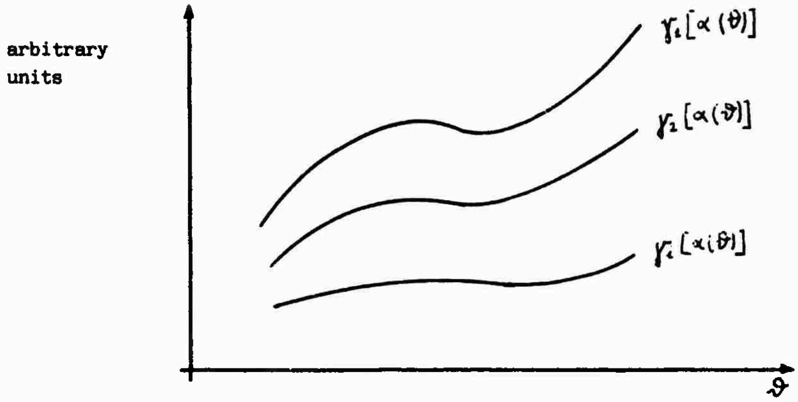
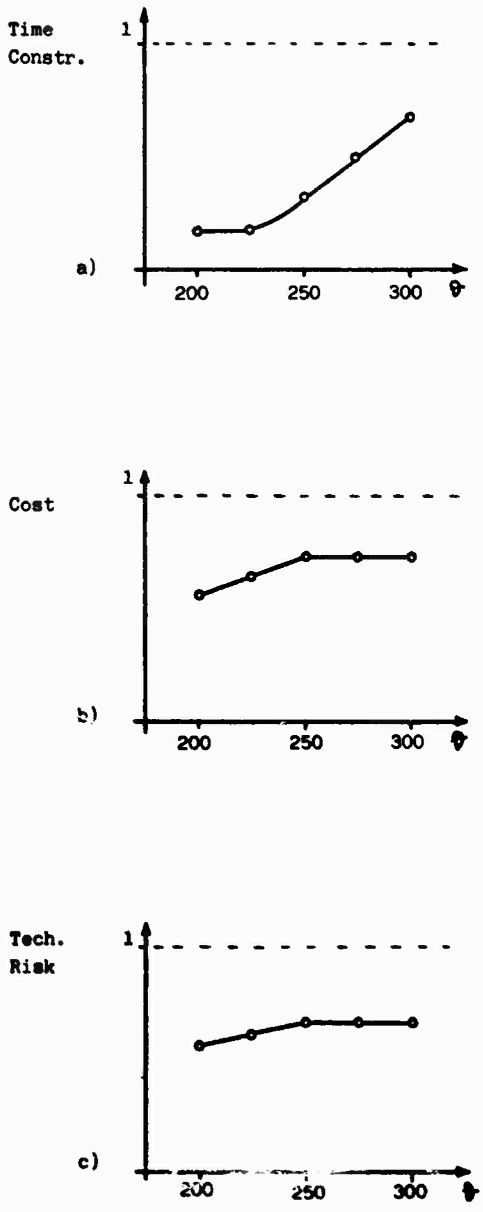


FIG. 1

Marginal Substitution Rate functions



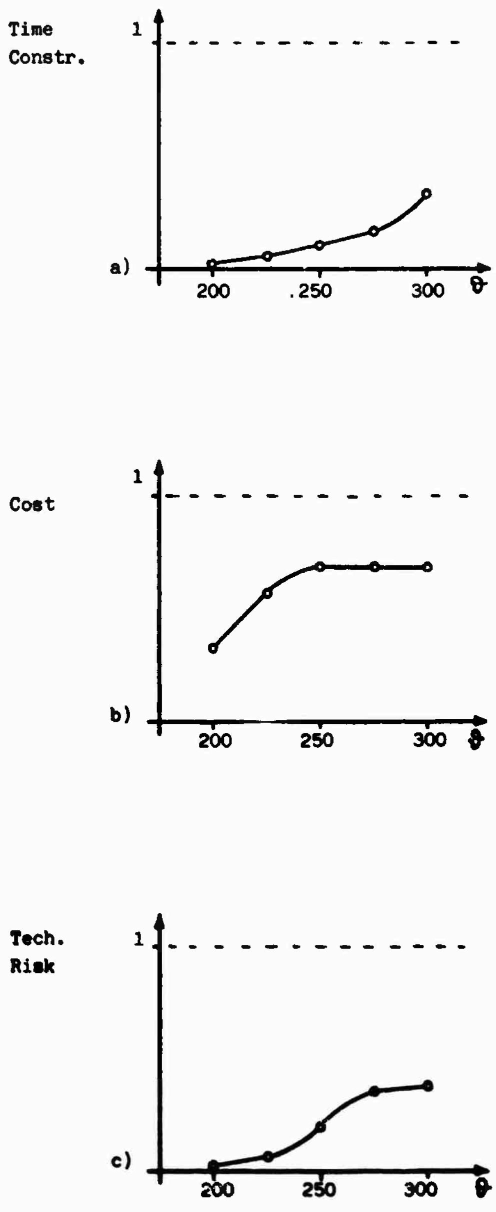


FIG. 2

MSR's for system type B
assuming resources variation (ϑ)

FIG. 3

MSR's for system type C
assuming resources variation (ϑ)

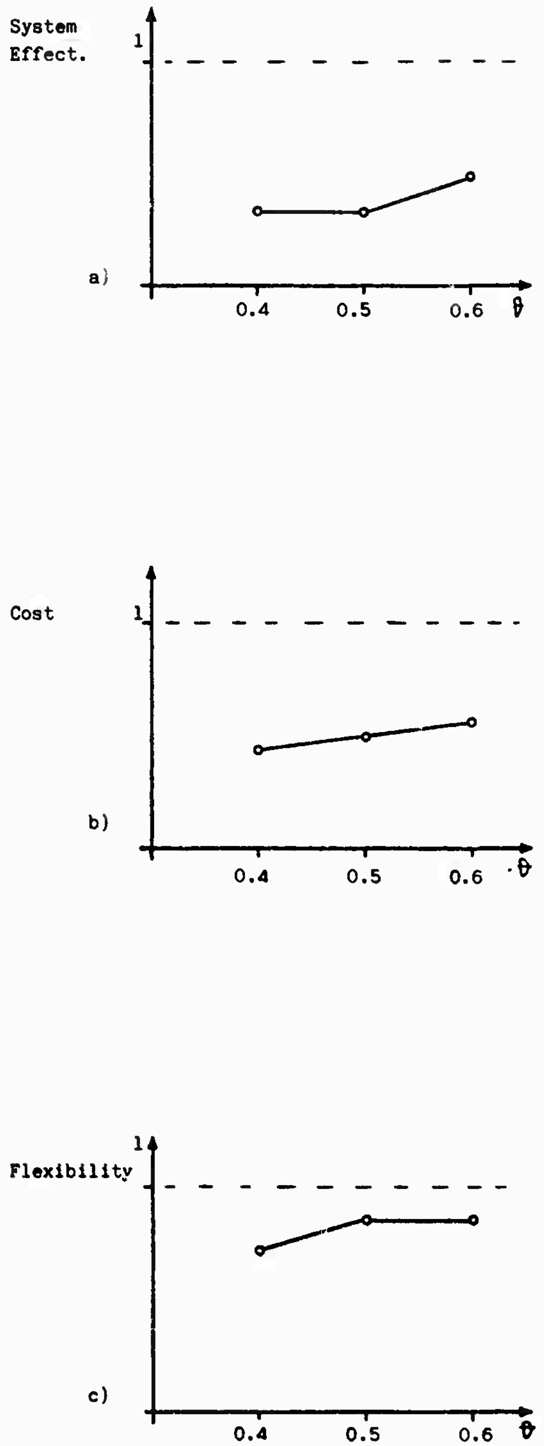


FIG. 4

MSR's for system type B assuming integration level variation (ϑ)

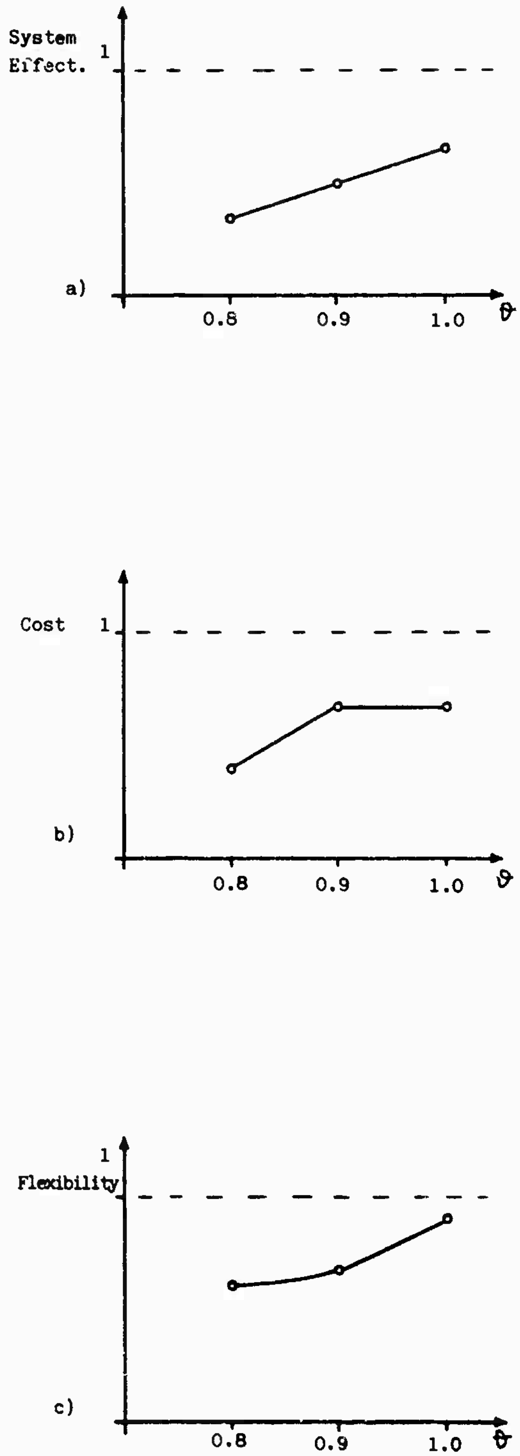


FIG. 5

MSR's for system type C assuming integration level variation (ϑ)

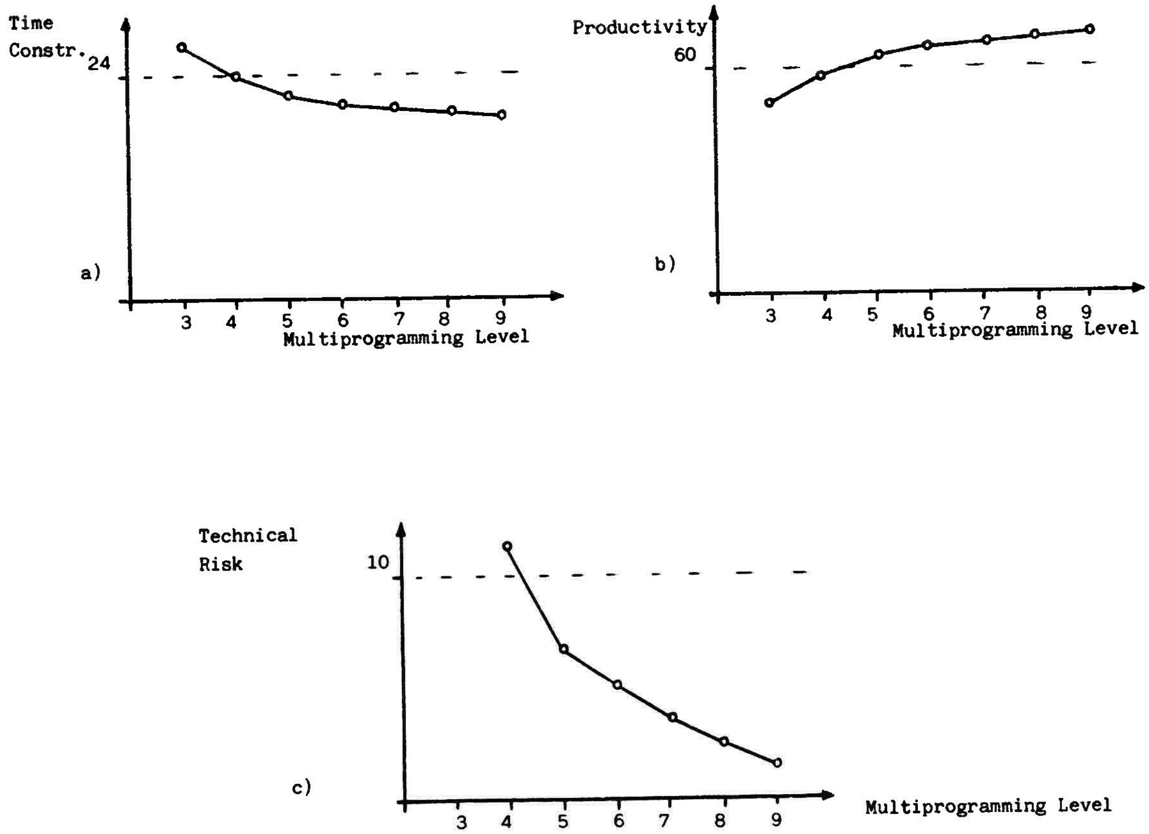


FIG. 6

MSR's for Host Computer Multiprogramming level variation

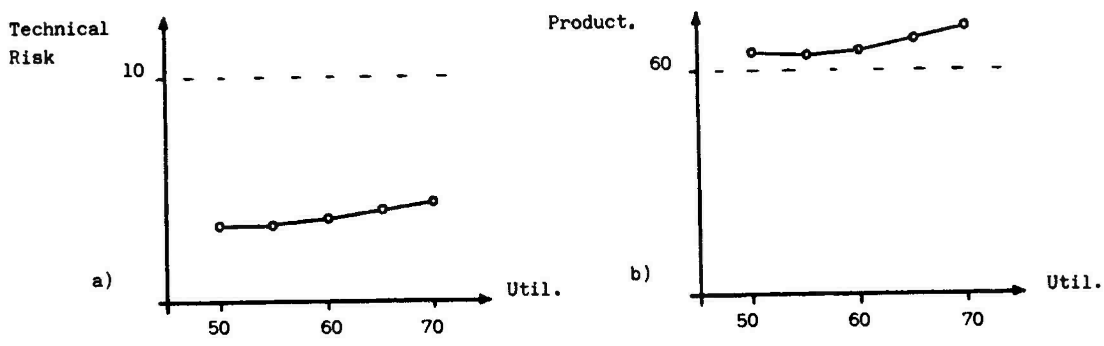


FIG. 7

MSR's for Airborne Computer Utilization variation

AFTI/F-16 - AN INTEGRATED SYSTEM APPROACH TO COMBAT AUTOMATION

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ABSTRACT

The Advanced Fighter Technology Integration, AFTI/F-16 Program is developing and flight validating advanced technologies which improve fighter lethality and survivability. The capability is achieved by the integration of mission task tailored, digital flight controls with a director-type fire control system and advanced target sensor/trackers into an automated maneuvering attack system.

The core technology in the AFTI/F-16 approach to this integrated system capability is the Digital Flight Control System (DFCS). Integrated with the on-board avionics system, the DFCS provides capabilities for maximum exploitation of flight/fire/weapon control and other subsystem integration.

Task automation as applied to the fighter mission will be evaluated with AFTI/F-16's Automated Maneuvering Attack System (AMAS). Radar and FLIR/Laser sensor/trackers provide precise targeting information in AMAS for both air-to-air and air-to-surface attack. Careful attention is given the pilot/vehicle interface through multi-function displays, wide field-of-view HUD, predictive HUD symbology and "hands-on" controllers. Voice Command is anticipated to be a key interface feature. The AMAS is expected to allow accurate weapon delivery from low altitudes ~~(below 100m)~~ while achieving increased survivability through maneuverability, the low altitude environment and stand-off delivery.

Flight testing of the DFCS began at Edwards AFB in August 1982. Flight testing of AMAS, including ordinance delivery, will be conducted in 1984-85.

The paper expands on the systems approach to the DFCS, avionics architecture, redundancy considerations, attack sensor integration, coupling of flight and fire control systems, weapon integration, crew station provisioning and automation concepts.

ACRONYMS AND ABBREVIATIONS

A/A	Air-To-Air
A/S	Air-To-Surface
ADPO	Advanced Development Program Office
AFTI	Advanced Fighter Technology Integration
AGL	Above-Ground-Level
AMAS	Automated Maneuvering Attack System
AMUX	Avionics Multiplex Data Bus
BIT	Built In Test
CADC	Central Air Data Computer
DE/CIS	Data Entry/Cockpit Interface Set
DFCS	Digital Flight Control System
DMUX	Display Multiplex Data Bus
EW	Electronic Warning
FCC	Fire Control Computer

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FCS	Flight Control System
FLIR	Forward Looking Infrared
FOR	Field-of-Regard
FOV	Field-of-View
g	Acceleration Due to Gravity
HUD	Head-Up Display
HMS	Helmet Mounted Sight
IBU	Independent Backup Unit
IFFC	Integrated Flight and Fire Control
IFIM	In-Flight Integrity Management
INU	Inertial Navigation Unit
LARAP	Low Altitude Radar Auto-pilot
LOS	Line-Of-Sight
MFDS	Multi-Function Display Set
MTBF	Mean Time Before Failure
OFP	Operational Flight Program
PVI	Pilot/Vehicle Interface
RALT	Radar Altimeter
S/T	Sensor/Tracker
SAIF	Standardized Avionics Integrated Fuzing
SWIM	System Wide Integrity Management
TF/TA/OA	Terrain Following/Terrain Avoidance/Obstacle Avoidance
TMD	Tactical Munition Dispenser
TSE	Target State Estimate
VCS	Voice Command System
VHSIC	Very High Speed Integrated Circuit
WAAM	Wide Area Anti-Armor Munition
WMUX	Weapons Multiplex Data Bus

1. AFTI/F-16 PROGRAM DESCRIPTION

The overall objective of the Advanced Fighter Technology Integration (AFTI)/F-16 Advanced Development Program is to develop and flight validate technologies which will improve fighter lethality and survivability. The AFTI/F-16 program provides for the development, integration, flight evaluation and demonstration of emerging technologies applicable to fighter aircraft in the critical, tactical environment of low-altitude attack and air-to-air combat. This is a joint program involving the United States Air Force, Navy, Army and the National Aeronautics and Space Administration (NASA). The AFTI/F-16 Advanced Development Program Office of the Flight Dynamics Laboratory serves as the responsible developmental agency. General Dynamics, Fort Worth Division, is the principal contractor responsible for system development. The Air Force Flight Test Center and NASA Dryden Flight Research Facility, supported by General Dynamics, are responsible for flight test operations.

The AFTI/F-16 development is being accomplished in two phases involving two periods of aircraft modification and two series of flight tests. The Digital Flight Control System (DFCS) is the core technology and as such is the primary technology development task in Phase I of the program. The DFCS development addresses flight path control and provides task-tailored, multimode control for operational versatility. The DFCS enables efficient use of 6 degree-of-freedom, decoupled aircraft control involving direct force modes and weapon line pointing. This part of the AFTI/F-16 program includes development of the demonstrator aircraft, with provisions for direct force control and weapon line pointing, cockpit development, avionics system integration, voice command evaluation and basic provisions for interface and installation of the Automated Maneuvering Attack System (AMAS) hardware. The July 1982 to

June 1983 flight test period will be accomplished to assess and validate the Phase I technologies. In Phase II, automated maneuvering attack is the key thrust in demonstrating increased weapon delivery effectiveness and survivability. The DFCS is coupled with a director-type fire control system. Target sensors/trackers, helmet sight and weapons interface automation are added. A key thrust is the evaluation of automation with respect to weapon delivery tasks. Flight testing is planned for the February 1984 to March 1985 period.

2. PHASE I - DIGITAL FLIGHT CONTROL SYSTEM (DFCS)

First flight of the AFTI/F-16 was successfully completed on 10 July 1982 (Figure 1). This significant milestone in the development of the AFTI/F-16 Phase I Digital Flight Control System, was preceded by a year of rigorous testing to validate hardware and computer software. The aircraft was ferried from General Dynamics/Carswell AFB TX to Edwards AFB CA and entered flight testing that will continue to June 1983.

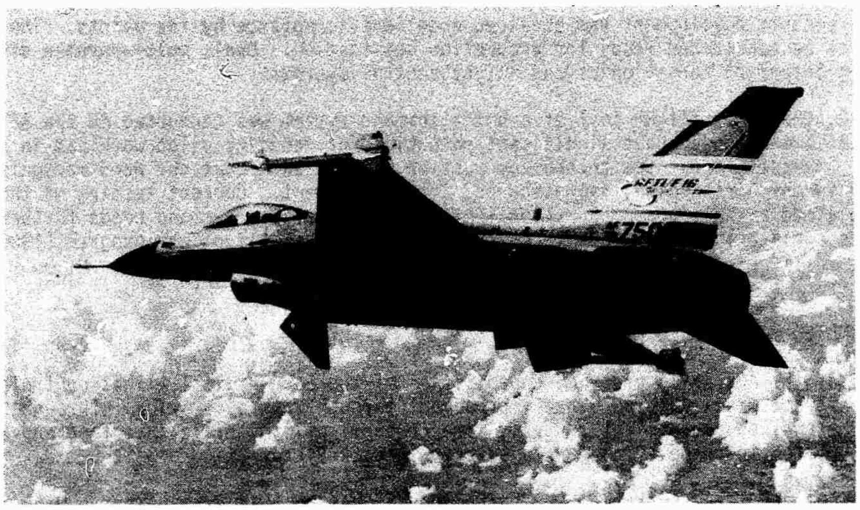

Figure 1 AFTI/F-16 First Flight - 20 July 1982

The AFTI/F-16 DFCS (Figure 2) is an advancement of the current state-of-art for digital flight control. The combination of computer hardware associated software and failure management techniques make it possible to use a tri-channel versus conventional quad-channel flight control system architecture. Advanced redundancy management techniques provide essentially two fail-operate capability, achieving a reliability equivalent to one loss-of control in 10^7 flight hours and one mission abort in 10^5 flight hours.

The Bendix BDX -930 computers employ "pipeline" architecture, 16-Bit micro-processors and operate together in an asynchronous mode. The advantages of decreased cost of ownership, weight and electrical power without compromise of system reliability are expected for the triplex redundant system. The design feature of identical software residing in each computer is another driver in reduced ownership cost.

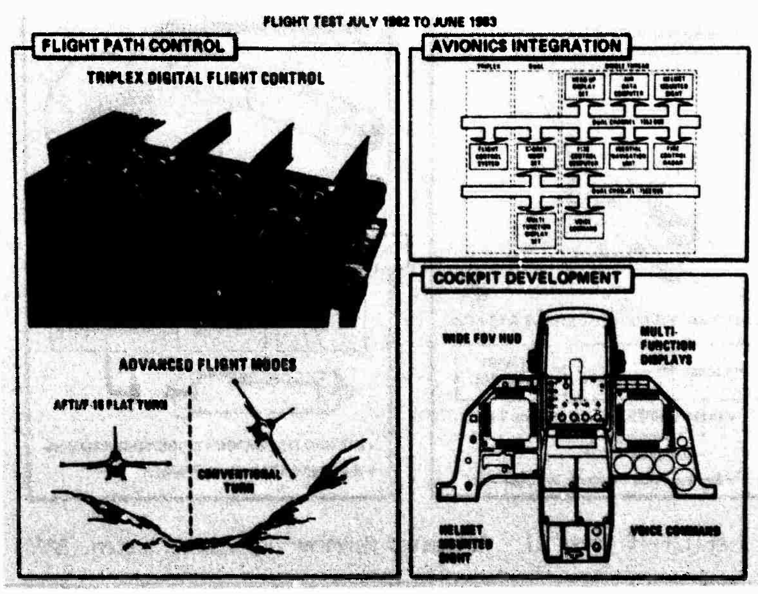

Figure 2 AFTI/F-16 Phase I - Digital Flight Control System (DFCS)

Flight testing to date is demonstrating that the digital flight control design goals are being met. Highly reliable operation is being demonstrated; supporting analytical studies and laboratory data indicate at least a 25 percent mean-time-between-failure (MTBF) improvement in the triplex digital system vs a quad digital system. With respect to quad analog system, a 2 to 4 times improvement in MTBF is indicated. The software intensive, triplex redundancy management design works; analytical studies indicate at least a 20 percent life cycle cost savings for the triplex versus quad-digital flight control system. Viability of flight control/avionics communication via multiplex data busses has been established. The multi-bus avionics architecture and software configurable system supports growth to automation functions and enhanced mission performance features. These will be flight demonstrated in an Automated Maneuvering Attack System during the Phase II of the AFTI/ F-16 Program (1984-1985).

A feature of the DFCS is task-tailored multimode flight control laws including the 6 degree-of-freedom, decoupled modes. This multimode control capability is a ten-fold increase over the F-16 analog flight control capability. All the modes have been demonstrated. Power approach control laws show a significant improvement over the standard F-16. Maneuver quickening and increased precision in flight path (for bombing) and pointing (for gunnery) control have been demonstrated through the unique multimodes. The automated maneuver flaps show cruise and maneuver performance improvement.

The AFTI/F-16 cockpit development has obtained excellent acceptance by the pilots. The wide angle, head-up display can be considered ready for production application. Dual, multi-purpose displays offer an effective pilot interface for avionics and flight control systems.

On 22 Dec 1982, the first flight test of a voice command system was conducted on the AFTI/F-16. We believe that Voice Command could have significant potential for reducing pilot workload in single-seat fighter aircraft. However, first the technology must be matured such that the word recognizer can reliably function in the harsh noise, vibration and 'g' environment. Current testing of the voice command system is aimed at this goal. Functional utilization of voice command needs further work to define appropriate applications. We hope to evaluate those in Phase II of the program (1984-1985).

3. PHASE II AUTOMATED MANEUVERING ATTACK SYSTEM

In this phase of the AFTI/F-16 program, capabilities of the core digital flight control system are exploited to demonstrate mission performance improvement through task automation. Through software integration, the attack sensors, flight control, fire control, pilot vehicle interface and weapons interface are integrated into the Automated Maneuvering Attack System (Figure 3).

Integrated flight and fire control (IFFC) technology is key to this development. With IFFC, a control loop is closed between the fire control and flight control systems; couplers are designed to automatically null weapon aim error. Full authority of the digital flight control system is available in the AMAS.

The potential of IFFC technology for improved weapon delivery has been vividly demonstrated in flight test on the IFFC F-15. While introduction of IFFC technology into fighter aircraft offer significant improvements in weapon delivery, careful attention to systems integration is necessary to assure usability of IFFC in real-world combat conditions. The AFTI/F-16 AMAS development focuses system integration and task automation for combat application. Thus, the integrated system design must be driven by the combat scenarios. (Figure 4).

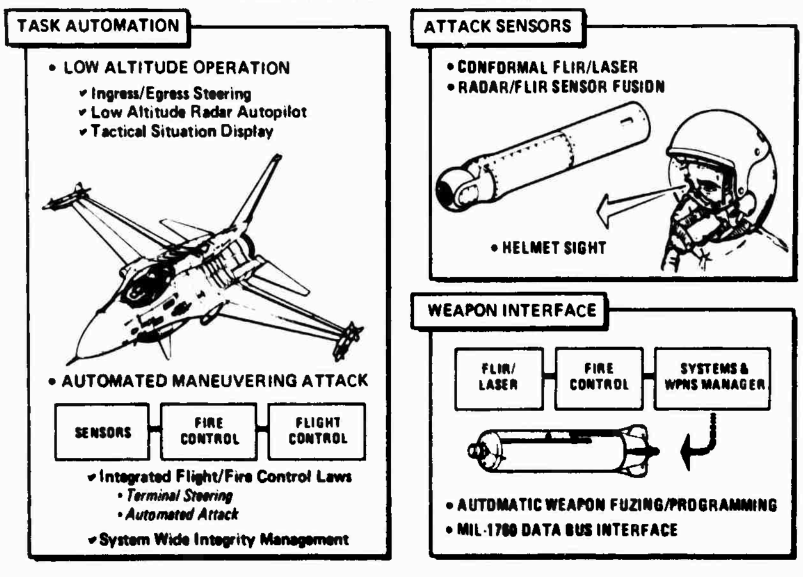

Figure 3 AFTI/F-16 Phase II - Automated Maneuvering Attack System (AMAS)

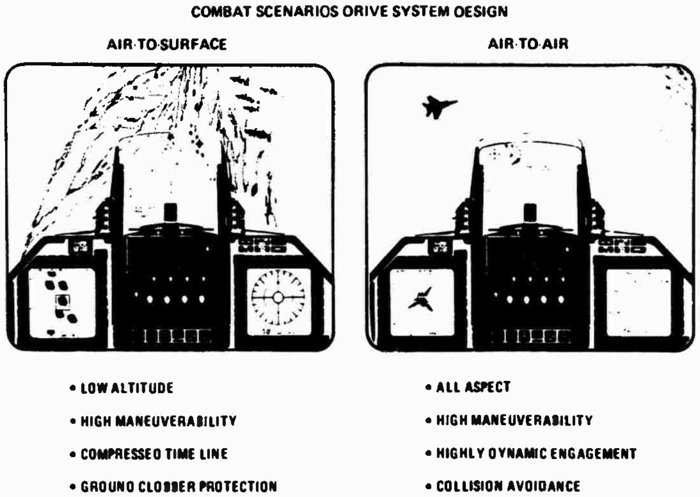

Figure 4 AFTI/F-16 AMAS Combat Scenarios

Combat Scenarios

An immediate need is for improved capability in fighter aircraft to fly low, day and night, and in weather, using terrain for cover from enemy defenses. AFTI/F-16 Phase II addresses this need in the logical first step of day attack; provisioning for extension of the technology to night attack is also considered. In addition, all-aspect air-to-air gun combat is a goal for exploitation of the Automated Maneuvering Attack System.

Air to-Surface. The AFTI/F-16 has the systems to demonstrate precision, low altitude air-to-surface maneuvering attack. Figure 5 illustrates a maneuvering attack scenario. The pilot expects to fly fast, low (under 100m, use terrain masking, maneuver with freedom and remain head out-of-cockpit. Today, requirements of this attack profile create work loads the impose intolerable demands on the pilot; the timeline is highly compressed and ground clobber is a significant concern while managing sensors and weapons. Here automation can be logically applied, reallocating tasks that saturate the pilot's attention and/or are beyond human limitations. The aim is to free the pilot to concentrate on target acquisition/identification, attack planning and threat avoidance, with the automated system working the flight trajectory, altitude control and attack guidance tasks.

The AMAS system is designed such that flight path control from engagement on ingress through weapon release and into egress, can be fully automatic. Automatic guidance is provided for both the set-up and actual weapon delivery. However, the pilot can intervene at anytime, adjusting either the ground track or altitude profile of the delivery to suit terrain or threat conditions. He can select semi-auto and manual control options.

The AMAS enables accurate weapon delivery while maneuvering. Bombs can be delivered from level, diving or lofted turning attack that provides standoff distance from the target and minimizes exposure to ground threats. To complement the maneuvering delivery, active control of a digitally fuzed Wide Area Anti-Armor Munition (WAAM) tactical munition dispenser (TMD) can be accomplished; fuze settings are automatically updated at the moment of weapon release rather than being pre-set at takeoff.

The maneuvering attack scenario drives design requirements to allow precision tracking of fixed and mobile targets. The key for accurate automatic weapon delivery is knowing precise target location. On AFTI/F-16, target location is provided through radar and FLIR/Laser sensor/trackers and inertial navigation unit (INU) coordinate information. A helmet mounted sight is used for sensor slewing to accomplish rapid off-boresight target designation. Very wide field-of-regard is desired for sensors, including the ability to look up, back and down, to enable freedom of maneuvering without sensor breaklock.

Air-to-Air. In the air-to-air scenario (Figure 6) an all-aspect gun envelope is the demonstration goal. With IFFC, high line-of-sight rate and front quarter engagements become realistic. This was vividly demonstrated with the PQM-102 drone kill by the IFFC F-15. AMAS will extend this capability by exploiting the full AFTI/F-16 capabilities: full authority digital flight control, advanced flight modes and a low noise FLIR/Laser sensor. An improved hit probability, over an aggregate of high angle off (front quarter), high line-of-sight rate and dynamic tail chase encounters, is anticipated. Automation is applied in sensor management, flight path avoidance and for nulling aim errors. An automatic collision avoidance maneuver and auto-trigger are also software design considerations. Here too, extreme wide field-of-regard for sensors is desired. Excellent sensor clutter rejection is needed to minimize target break-lock. Low "noise" sensor tracking/ranging is desired to reduce filter lags in the fire control computations and facilitate tracking in highly dynamic engagements.

Demonstrator Configuration

Figure 7 illustrates the AMAS demonstrator configuration. Equipment added to the Phase I - DFCS demonstrator include the FLIR/Laser sensor/tracker (S/T) set, 360 degree roll coverage radar altimeter, Standardized Avionics Integrated Fuzing (SAIF) and helmet mounted sight.

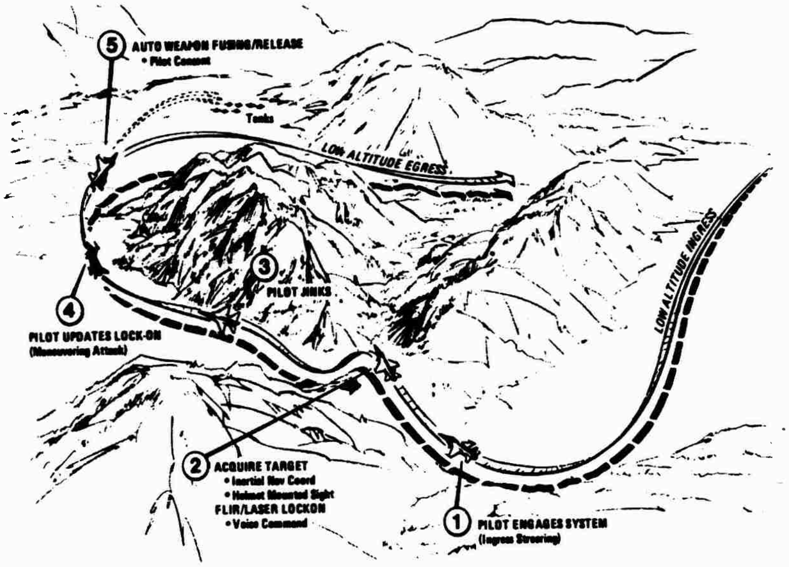

Figure 5 AFTI/F-16 Automated Maneuvering Attack

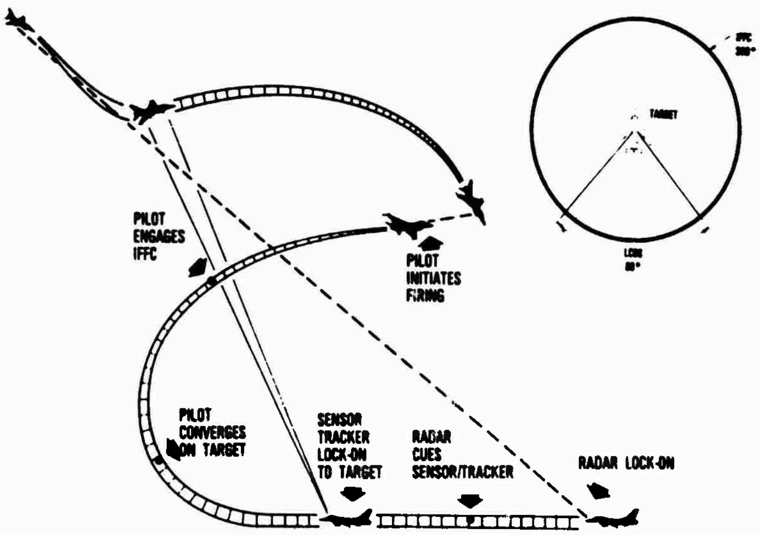

Figure 6 AFTI/F-16 Air-To-Air Gunnery

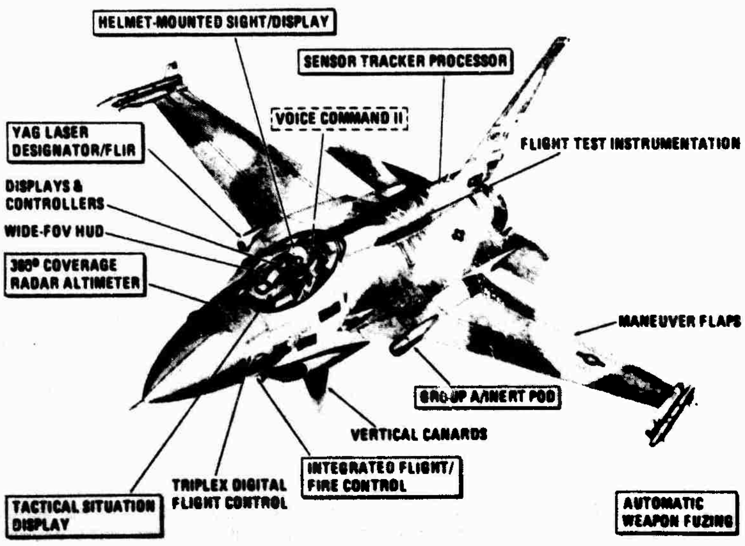

Figure 7 AFTI/F-16 AMAS Configuration

The FLIR/Laser was chosen because of the excellent clutter rejection and day/night capability. Special attention was given to minimize aircraft performance loss and to provide the required wide field-of-regard. The sensor/tracker set was functionally partitioned such that only essential sensor functions are provided by the externally mounted head unit; target state estimator, tracking, fire control and environmental control functions are provided by internally housed aircraft equipment. The conformal strake mount and small sensor head diameter (nominal 20cm) minimizes drag over the operating mach range; supersonic performance is not sacrificed with the dual sensor head installation.

The above-ground-level (AGL) altitude hold autopilot operates on a system altitude derived from the sensor compliment of radar altimeter, fire control radar, the sensor/tracker and the inertial navigation unit. The radar altimeter measures current altitude with full (360 degree) roll attitude capability provided by multiple antennas. Combined with the other sensor data, a safe AGL altitude hold profile is generated through the digital flight control system. The purpose of this autopilot mode is to reduce pilot workload , allowing the pilot to pay additional attention to target acquisition during ingress, in the Edwards/Nellis AFB flight test environment. This is not a full terrain-following system. However, we consider automatic terrain following/terrain avoidance to be an important requirement, and another critical technology need, for operational employment of AMAS with night/all weather attack capabilities.

The approach to integration of these systems is depicted in Figure 8 and is the subject of the following discussion.

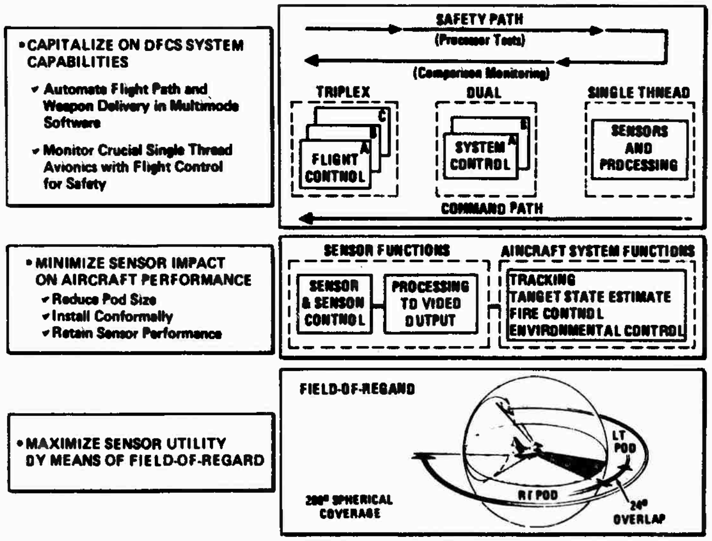

Figure 8 AFTI/F-16 AMAS Approach To Weapon Delivery System Integration

System Architecture

The AMAS system architecture was developed to provide proper functional partitioning, minimal interface parameters, and minimal system transport delay to maximize system performance and integration efficiency. As shown in Figure 9 the system is structured around three MIL-STD-1553 digital multiplex busses that provide the majority of the subsystem communications. These MUXs, Avionics (AMUX)), Display (DMUX), and Weapons (WMUX), operate with a basic 50Hz rate and have a primary and backup bus controller. Subsystems have been partitioned between the AMUX and DMUX busses to provide for a well balanced bus loading. Inertial data in analog form, for axis transformations, are some of the few parameters not carried by the MUX bus structure.

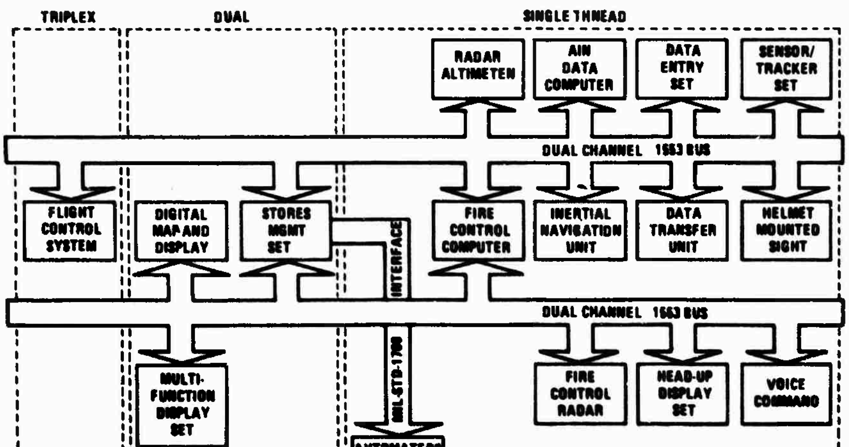

Figure 9 AMAS Multi-Bus Architecture

Modifications to existing operational flight program software are required for the flight control system, the fire control computer, stores management set, head-up-display, multi-function display set and the fire control radar. Figure 10 lists functional assignments to various AMAS system OFP's.

SENSOR/TRACKER CONTROL TARGET OETECTION ANO LOCK-ON TRACKER RATE AIOING/COASTING TARGET STATE ESTIMATOR IFIM & BIT	– Sensor/Tracker OFP
SENSOR MANAGER AIR-TO-AIR DIRECTOR FIRE CONTROL BOMBING FIRE CONTROL OISPLAY CONTROL AIRCRAFT STEERING CALCULATIONS IFIM & BIT	– Fire Control Sys OFP
COMMANO COUPLER FLIGHT CONTROL COMPUTATIONS LOW ALTITUOE RAOAR AUTOPILOT IFIM & BIT	– Flt Control Sys OFP (FLCC MOD)
IFFC MOOE SELECTION	– Systems Mgmt System OFP – MFOS OFP – DE/CIS OFP

Figure 10 Functional Allocation To AMAS OFP's

System Design

The functional partitioning of the AMAS system, illustrated in Figure 11, was developed through consideration of interface conditions, proliferation of OFP changes from a single system modification, data transport delays, system reliability, and system safety. The air-to-surface modes are designed to operate in the low altitude attack regime that requires flexible target acquisition, accurate target tracking, low altitude/high bank angle flight conditions and high load factor turning delivery algorithms. Figure 12 illustrates design approaches to each of these requirements. The air-to-air mode is designed with a director fire control solution nulled by the decoupled flight control system that provides high angle-off gun firing opportunities and a maneuvering target tracking capability.

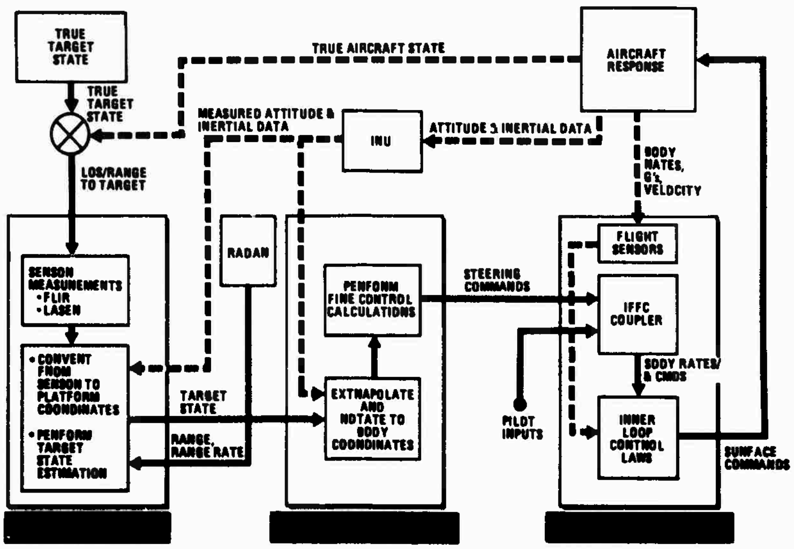

Figure 11 AMAS Functional Partitioning

Sensor/Tracker

The AMAS sensor/tracker is being procured by General Dynamics from Westinghouse Corporation. The sensor is an 8 to 11.5 micron FLIR with three selectable fields-of-view. It generates 525 raster line video that is displayed on the pilots multi-function displays. The video tracker has both correlation and centroid track capabilities with auto acquisition and adaptive gates. The laser is a Neodynium Yag 1.06 micron laser with a variable pulse rate and beam diffusion. It also provides a quadrant track capability to enhance FLIR lock-on. The sensor/tracker provides a full 120 degree field-of-regard with no vignetting and in the dual sensor aircraft configuration has no aircraft obscuration. The target state estimator in the sensor/tracker is a nine state Kalman filter with variable gains structured around a platform axis system. The sensor/tracker has seven major modes of operation (Figure 13) and is primarily commanded by the fire control system.

TARGET ACOUISITION
- HMS PERMITS LARGE OFF BORESIGHT ANGLE DESIGNATIDNS
- RADAR ALLOWS STANOOFF/NIGHT TARGET ACQUISITIDN
- HUO PROVIDES ACCURATE LOW OFF ANGLE OESIGNATIONS
- PREPLANNED TARGET OR TARGET OF OPPORTUNITY DPTIONS

ACCURATE TARGET TRACKING WITH SENSOR/TRACKER
- LARGE OFF BORESIGHT ANGLE TRACKING (120°)
- ACCURATE LASER RANGING AT LOW ALTITUDES
- TARGET IDENTIFICATION AT LONGER RANGES
- MECHANIZATIDN OPTIMIZED FDR LOW ALTITUDE DELIVERIES

LOW ALTITUDE/HIGH BANK ANGLE OPERATION
- IFIM, SWIM DESIGNED FOR LOW ALTITUDE OPERATION
- LDW ALTITUDE RADAR AUTOPILOT INCLUDED TO REDUCE PILOT WORKLDAD
- 360° RDLL CDVERAGE FROM RADAR ALTIMETER FDR HIGH BANK ANGLES

HIGH G TURNING DELIVERY ALGORITHMS
- DESIGNED FOR MAXIMUM INGRESS MANEUVER FLEXIBIILTY
- AUTD INGRESS STEERING FOR TURNING DELIVERY SET UPS
- AUTDMATED 3D TURNING BOMBING

Figure 12 AMAS Low Altitude Design Features

- **STANDBY (Head Stowed)**
- **READY**
- **CUE**
  - **Scan**
  - **Nutate**
- **A/A TRACK**
  - **Laser Quadrant Tracker**
  - **Centroid Track**
  - **Point Track**
- **A/G TRACK**
  - **Scene Track**
  - **Target Track**
  - **Track Adjust**
- **COAST**
- **BIT**

Figure 13 AFTI/F-16 Sensor/Tracker Modes

Fire Control System

The fire control system provides several essential elements in the AMAS system: the sensor manager, the air-to-air director, the curvilinear or turning bombing director, ingress steering and collision avoidance determination.

The sensor manager function monitors the on-board avionics sensor complement to insure their integrity and that sensor support is adequate for the closed loop integrated flight and fire control operation. The sensor manager also determines system altitude (above ground level) from the sensor complement(a minimum of two sensors is required) to furnish to the low altitude hold autopilot. The antenna switching for the 360 degree bank angle radar altimeter is also accomplished by the fire control computer.

The air-to-air director algorithm is of second order and is based on a closed form solution of bullet-time-of-flight for the 20MM projectile. The original curvilinear bombing algorithm used in design of the IFFC F-15 system has been modified to increase weapon delivery accuracy. A predetermined release range is established, by the pilot, and the algorithm establishes the aircraft load factor and bank angle to culminate in a weapon delivery at that range. Ingress steering is also provided that will generate a path to setup a curvilinear attack regardless of where the target is located at the time of system engagement.

Collision avoidance is calculated for both air combat and ground avoidance. The ground avoidance calculation considers the aircraft speed, attitude, altitude, and load factor capability. In any automated air-to-surface operation, this algorithm is active and will trigger an automated fly up to provide a safe, selectable floor under the aircraft's operation.

Flight Control System

In the AMAS system the triple redundant flight control system contains the IFFC couplers and control laws that implement the fire control system command or error signals, the self contained fly up, and the System Wide Integrity Management (SWIM) manager.

The flight control couplers take the fire control signals and convert them into signals compatible with the AFTI/F-16 inner loop control laws (i.e.-load factor, pitch rate, roll rate, yaw rate). The air-to-air couplers take fire control predicted azimuth and elevation miss distance and inertial gun rate and generate, through a proportional plus derivative control loop, inputs to the DFCS decoupled flight control laws. The flight control system attempts to null the errors and match the predicted gun rate. Elevation errors are nulled through body axis pitch rate while azimuth errors are nulled through roll rate and yaw rate motions.

The bombing couplers accept bank angle and load factor commands from the fire control system. These commands require little modification to make them acceptable to the flight control system's decoupled control law structure. All the couplers provide rate and magnitude limits for safety and redundancy management considerations.

The System Wide Integrity Management (SWIM) function (Figure 14) is to insure that the system condition is acceptable for engagement and operation in the selected closed loop IFFC mode and if not, to disallow or terminate the engagement in a safe manner. The SWIM final decision is always accomplished in the Flight Control System (FCS). The redundant nature of the FCS makes it most suitable as the SWIM manager. In addition to data received from other subsystems (Figure 15), the FCS does self contained checks and system crosschecks to verify proper operation or status.

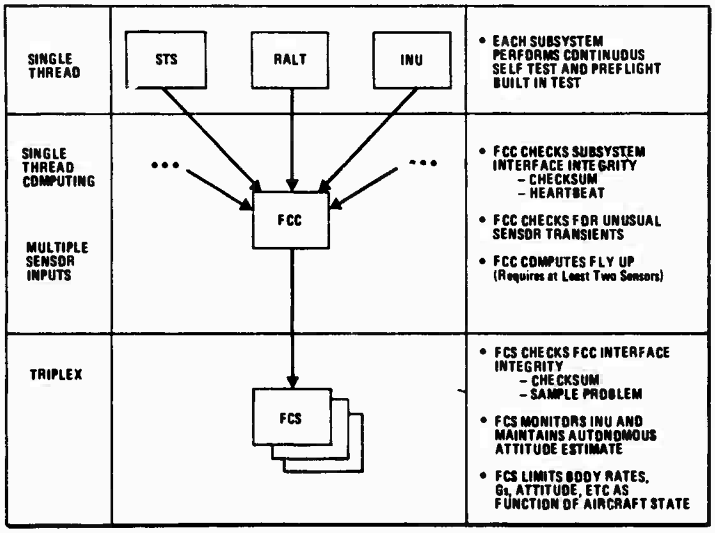

Figure 14 System Wide Integrity Management (SWIM)

- **FIRE CONTROL COMPUTER SELF TESTS AND MUX TESTS**
  - Existing AFTI/DFCS FCC Tests
- **FIRE CONTROL COMPUTER CROSS CHECKS**
  - Sensor/Tracker (LOS, TSE)
  - INU (Velocities, Accelerations, Altitude)
- **SENSOR/TRACKER SYSTEM SELF TESTS**
  - Similiar to FCC Self Tests Plus Laser Tests
- **FLIGHT CONTROL SYSTEM SELF TESTS**
  - Existing AFTI/DFCS Tests
- **FLIGHT CONTROL SYSTEM CROSS CHECKS**
  - INU (Altitude)
  - CADC (Velocity)
  - FCC (Operating)
  - Self Test Discretes Monitor

Figure 15 In-Flight Integrity Management

System Safety

Several system safety design features have been incorporated into the AMAS system design. A summary of these features is presented in Figure 16. Engage and disengage requirements must be satisfied in the triple redundant flight control system. Additionally, the pilot always has control override authority and multiple disengagement options. To provide a safe floor for all air-to-surface operations, the automated fly-up is provided upon exceeding the ground avoidance criteria or upon experiencing a system failure state within prescribed altitude regions. Aircraft structural protection is also provided by the inner loop control laws of the flight control system.

- ENGAGE/OISENGAGE REQUIREMENTS IN REOUNDANT FLCC'S
  - Mode Selected
  - Self Test Oiscretes Good
  - Engage Enable From All Monitors
  - Collision Avoidance Satisfied
  - Attitude Data Good
  - FCC Operating
- REOUNDANT IFFC PAOOLE SWITCH DISENGAGES SYSTEM MANUALLY
- PILOT HAS OVERIOE CAPABILITY AT ALL AUTHORITY LEVELS
- IFFC COMMAND LIMITS, BY AXIS, MAY BE SELECTED
- DFCS INNER LOOPS PROVIOE STRUCTURAL PROTECTION
- LASER FIRING INHIBITED BY TRACKER PROCESSOR AND FIRE CONTROL COMPUTER
- FLY-UP PROVIDED UPON EXCEEDING GROUND AVOIDANCE CRITERIA OR EXPERIENCING A SYSTEM FAILURE STATE

Figure 16 System Safety Design Features

Pilot/Vehicle Interface

The AFTI/AMAS cockpit displays and controls have been optimized to decrease pilot workload and increase his efficiency during the AMAS weapon delivery mission phases. The cockpit front panel (Figure 17) provides three multi-function displays and a HUD with display symbology designed for the AMAS missions. All pilot actions during the attack phase are thru hands-on switches on the throttle or the side stick controller. Mission phase selection is provided by pressing a single button on the HUD control panel. In the air-to-surface low altitude regime the pilot must be presented predictive displays as to the aircraft attack trajectory and release conditions as well as the weapon delivery solution. Figure 18 shows the HUD symbology for the AMAS attack profiles. The predictive profile is displayed towards the left side of the HUD; the attack symbology is displayed in the center. The predictive display shows the predicted flight trajectory (start, current position, apex, release) and weapon release conditions (dive angle, release and recovery altitudes). The attack symbology displays the load factor and bank angle, both commanded and actual, to achieve the desired release conditions. This symbology is amenable to manual as well as automated attacks. The wide field-of-view (15 X 20 degree instantaneous) facilitates placement of this symbology on the HUD. The two upper multi-function displays present sensor video as well as system status and control. Video from the FLIR or radar sensor/trackers can be selected by the pilot, hands-on, at anytime. Target designation and cursor corrections are easily accomplished through these displays. The lower display is a Tactical Situation Display featuring a moving map (film reader) format to assist in target ingress and egress.

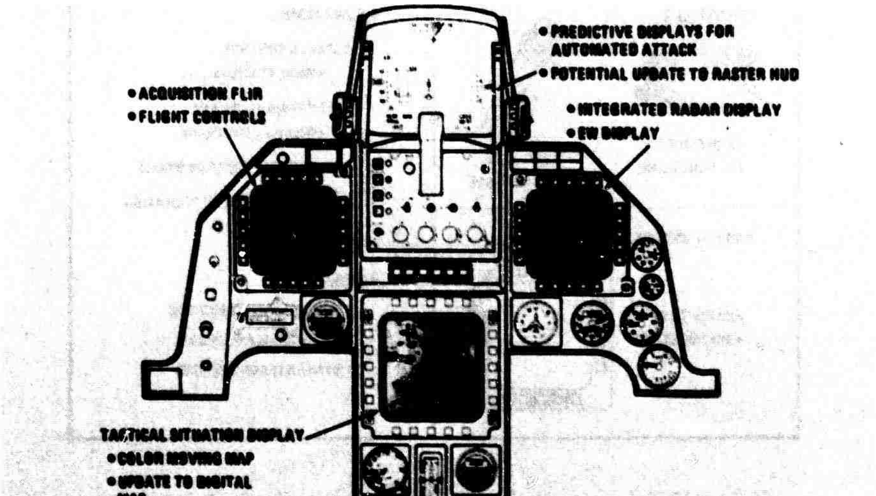

Figure 17 AFTI/F-16 Cockpit Displays

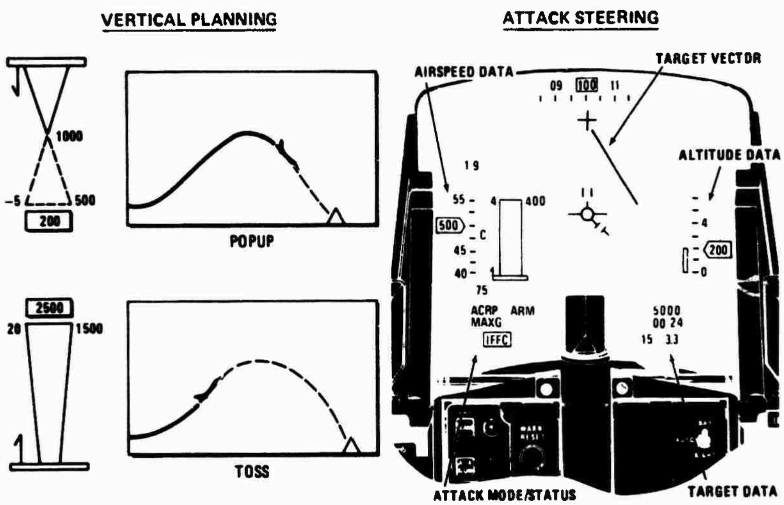

Figure 18 AMAS Predictive Display Sumbology

Helmet Sight.

A significant part of the AMAS system is a helmet sight that will enable rapid head-up and hands-on off-boresight target designation. This feature is considered essential in order to reduce pilot workload to a level where the AMAS weapon delivery can be effectively accomplished in a single-seat fighter. The pilot looks at the target of interest, pushes the "designate" button on his sidestick controller, and the sensors will slew to the designated direction; he can expect a coarse sensor lock-on (target can be found within the sensor video field-of-view). Precise correction to target designation would then be made through a throttle-mounted cursor control or voice command with MFD sensor video. Reverse cueing of target location (e.g. - locked-on sensor) is also possible with the helmet sight to assist the pilot in visual acquisition of the target.

Voice Command.

Another dimension to an interactive pilot/vehicle interface is through voice command. Careful attention was given in designing hands-on controllers for AFTI. However, the number of switches and functions (Figure 19) have reached the limit of reasonable operability. Voice can be the next threshold in cockpit operation, giving the fighter pilot a true head-up, hands-on control capability and reducing or redistributing pilot workload. Voice may be a key element in single-seat operation of a fighter on an AMAS-type mission scenario. Unfortunately, we do not know at this time if additional voice command efforts beyond Phase I will be funded for Phase II - AMAS evaluation.

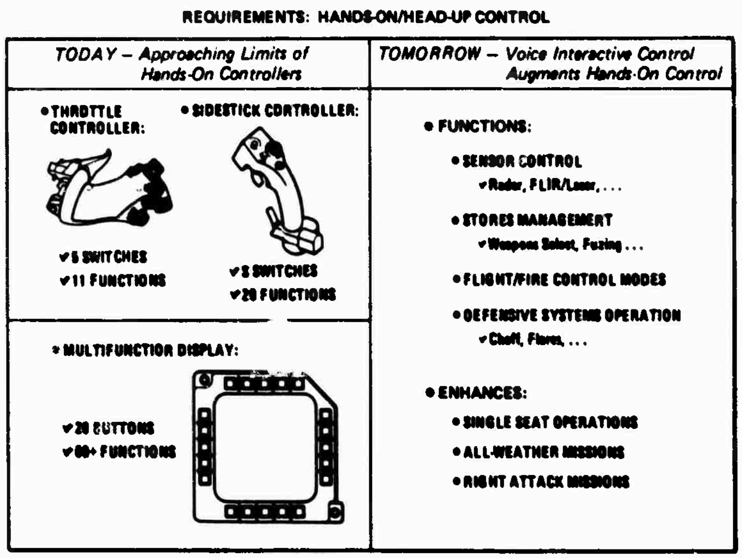

Figure 19 Voice Command - The Next Step in Cockpit Operations

4. AUTOMATION GROWTH

The AFTI/F-16 program represents a step-by-step development process that could rationally lead to a single-seat night attack demonstration (Figure 20). The DFCS development provided a base with which to automate the flight path control function. In AMAS, the low altitude radar autopilot (LARAP) simulates a terrain following capability in a near flat earth environment. The real need is for fully automatic/redundant terrain following/terrain avoidance/obstacle avoidance (TF/TA/OA) that can ensure safe low-altitude (below 100m) high-g turning flight. We believe that through multiple, complementary sensor data correlation (e.g. - agile beam radar, CO_2 laser radar, full-roll radar altimeter, stored terrain data base), with careful attention to system safety and the pilot-vehicle interface, this capability can be available day and night. In order to effectively accomplish the complementary data correlation, Very High Speed Integrated Circuit (VHISC) technology becomes a requirement. A helmet display with head-driven FLIR imagery could be an essential technology for pilot confidence.

Automation of the navigation function is an equally significant task. In a joint effort with the U.S. Army, AFTI/F-16 is planning to evaluate a stored data base, digital moving map. The digital map can increase situational awareness during TF/TA flight and through terrain correlation could provide autonomous precision navigation. The digital map display could also function as a tactical situation display locating threat lethality envelopes and survivable corridors. Further application could be made for optimum route planning, using terrain masking, threat penetration and time of arrival information. Complementary systems such as JSTARS (Joint Surveillance and Target Attack Radar System) become an important adjunct for providing real-time targeting information with the auto-nav functions.

Automation of the engagement function is the key area addressed by AMAS; auto attack steering and high-g turning weapon delivery is the thrust. In the day, a helmet sight can be used for target designation. At night and in weather, an automatic target recognition capability becomes very important. Head directed night vision and FLIR devices with the helmet sight/display could be useful.

Automation in the weapons area is addressed in AMAS with the Standardized Avionics Integrated Fuzing (SAIF) for area munitions. The weapons MUX bus with MIL 1760 interface compatibility can provide automatic fuzing and controlling capabilities for a variety of unguided and guided weapons.

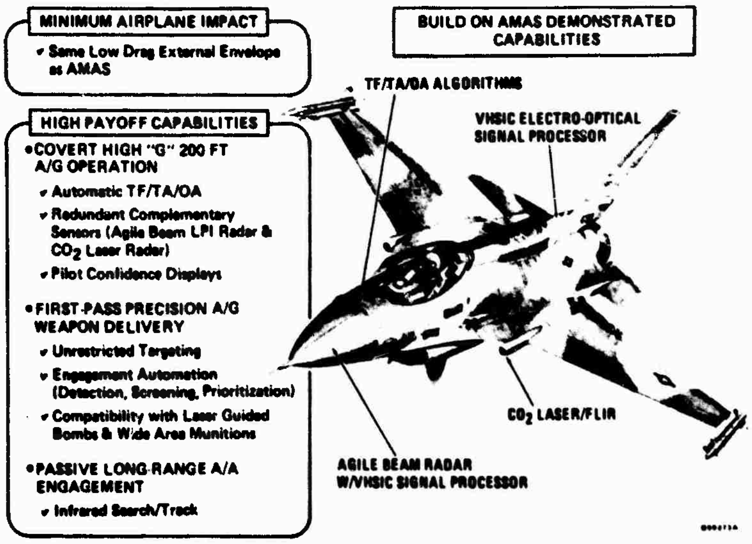

Figure 20 Potential Growth To Night Attack Capability

5. CONCLUSION

In conclusion, we believe that the AFTI/F-16 Automated Maneuvering Attack System development is an important approach for development of the integration technologies and will provide an engineering perspective that forms a valuable base on which to build. We recognize that AFTI/F-16 AMAS is not an end product, but is an invaluable flight research tool with which to build and sort the benefits of combat automation.

DISCUSSION

J.F.Irwin, Ca

(1) Shouldn't the Horizontal Situation Display (HSD) be moved up in the HUD Control space to optimize the Head-Up/Head-Down transition problem?

(2) During low altitude TF/TA weapon delivery the pilot should maintain a head up attitude: A head up FLIR implementation would be a good subject for near term evaluation.

(3) How is the 360° Doppler Altimeter implemented in the antenna configuration and how is switching from one to another implemented?

Author's Reply

(1) I agree the HUD central panel is a terrible waste of valuable cockpit display space. However, the current HUD design would preclude moving the HSD up, even if cost did not. Maybe that plate displays of the future will make your idea feasible; or, a helmet display may obviate the need for a HUD.

(2) LANTIRN does have a raster HUD for FLIR display. We would like to do work in this area, but it is not in the current program.

(3) The 360° Radar Altimeter is implemented with four antenna pairs located around the aircraft, i.e. top, bottom and both sides. The fire control computer performs the antenna switching based on aircraft roll attitude. The aircraft roll attitude is derived from the Inertial Navigation Unit that is closely monitored by the redundant flight control system.

W.H.McKinlay, UK

It would be interesting to know how the system handles discontinuities, e.g. when the pilot intervenes and takes over manual control or wishes to regain an automatic profile, going from manual to automatic.

Author's Reply

The pilot can override the automated system at any time. During these periods of pilot override the fire control equations are continuously calculated using the present aircraft flight conditions. When the pilot releases the control back to the automated system through reduced stick forces, the automated system has a correct weapon delivery solution from the aircraft current position and flight conditions.

P.Bied-Charreton, Fr

(1) With the electro-optical pod, do you plan to make air-to-air tracking, in conjunction with radar, for instance for target identification?

(2) HUD: If the need for wide angle (holographic) HUD is only to present more data in the FOV edges, why spend so much? Would it be simpler and cheaper to have 20 by 20 degrees real HUD, and put the data in other HDD (level display)? Then the need is only for 20 degrees TV raster/stroke HUD, possible combined with helmet mounted sight.

Author's Reply

We are not specifically working on target I.D.; however, our narrow field-of-view FLIR can give about a 10 X telescope to assist target I.D. In air-to-air, sensor management (radar + FLIR) is automatically following target designation. The AFTI/F-16 HUD is 20° x 25° conventional optics. With a HDD, the eye must focus inside the cockpit – an advantage for the HUD where symbology focus is at infinity. We believe that helmet displays have potentials. Bulk and weight of current designs somewhat inhibit use in the high 'g' fighter environment, although some cursory testing shows that this is not an overwhelming problem.

J.Mitchell, UK

In order to increase night attack capability have you considered the use of pilot's night vision goggles, or if not, what was the reason?

Author's Reply

They are currently not in the programme although certain people have considered them. The current programme is day-only. We hope to continue the technology development to night attack. This task would include to consider goggles and/or helmet display devices.

C.Maureau, Fr

Concernant l'amélioration d'efficacité en combat qui peut résulter de l'amélioration des visualisations integrées dans le système, est-il exact de dire que vous la recherchez:

- d'abord, par l'emploi d'un viseur de casque permettant d'accrocher rapidement des senseurs sur la cible
- ensuite, en ce qui concerne le "Head Up Display", plus a partir d'une modernisation du "software" et de la symbologie associée, que par un elargissement relatif de son champ?

Author's Reply

- The helmet sight provides rapid sensor (radar and/or FLIR) cueing (off-boresight) to obtain target designation. Sensor control is then automatic with the pilot flying convergence to where the automatic system can then complete the precision weapon delivery task. Helmet displays are believed to have additional merit for head-out-of-cockpit operation in the future – this is not currently in the AFTI/F-16.
- The wide FOV HUD accommodates spreading of symbology to make it more usable to the pilot. It should be noted that in high angle-off A-A gunnery and maneuvering A-S attack, the target may not enter the HUD FOV until the last few seconds. A larger combiner glass does not significantly improve the pilot aiming capability for this situation. Again, the advantage is for providing space for "planning" data to allow the pilot to manage his weapon delivery task.

G.Hunt, UK

The AFTI system appears to be inherently rather costly. The philosophy advocated in the Keynote Address is towards a reduction in Avionics Cost. Your comment would be appreciated.

Author's Reply

First the triplex digital flight control system represents an approach for LCC savings (min. hardware for 2 fail-operate capability) over other analogue and digital approaches. Plus, it provides a magnitude increase in mission-capability through software integration. Second, what is the measure of cost? Reducing avionics will certainly reduce cost – but will it put bombs on target and can you survive? Combat losses are very costly, as it is not to achieve mission goals. AFTI aims at improving survivability through the automatic techniques (stand off weapon delivery, low level attack, turning delivery, etc.) AFTI also aims at increased delivery effectiveness (killing targets) including use of low cost, "dumb" bombs and cannon.

Another aspect is the FLIR sensor integration approach. Both A-A and A-S capabilities are maintained (sensor field-of-regard and aircraft performance) in the single airplane. Maximum use is also made of on-board aircraft sub-systems, rather than duplicating functions in a bolt-on pod. Only essential unique sensor functions are packaged with the sensor head.

Finally, we can all agree on the need to reduce avionics costs. I have heard many good ideas for so doing during this meeting. But this does not necessarily mean to reduce avionics capability. Mission requirements are extending to night and all weather operations with even increasing threat capabilities. We must achieve the capability to do the mission requirements – then let us do it as cheaply and simply as possible.

One afterthought – AFTI is not a prototype. It is a technology testbed, research vehicle for sorting ideas on how to best do the perceived job.

R.Westley, Ca

Concerning "Voice Command", could you comment on the size of the vocabulary required in voice command and the present outstanding problems of voice command in the AFTI cockpit?

Author's Reply

Current system in test has 36 word vocabulary, but we are using only about 10 words for test efficiency. Specification for future system would not likely exceed 200 words. Use of syntax will help limit size of vocabulary needed. Need to keep vocabulary required of pilot to be simple, easy to use and flexible – not rigid in format and process.

AD P002864

CONCEPT OF A FIGHTER AIRCRAFT WEAPON DELIVERY SYSTEM

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SUMMARY

Modern fighter aircraft carry, beside various types of bombs, more and more "intelligent" weapons. In this context the development of a Stores and Missile Management System has to take into account the requirement from the operational/tactical considerations as well as the optimal usage of advanced electronic equipment together with a growth and adaption capability in both areas. On the basis of existing weapon delivery systems this paper discusses some possible trends in weapon development (i. e. more intelligent fire-and-forget missiles) and weapon control systems development (i. e. Mil-Bus 1553 B, programmable weapon management computer) together with the integration problems of a complete aircraft weapon delivery system from the planning stage via equipment and subsystem development to rig and on-aircraft testing up to first flight test experiences.

Fig. 1: Weapon System Tornado

1. INTRODUCTION

The weapon history has been strongly influenced by milestones as the development of gun-powder, tanks, aircraft and submarines or Radar and Electronic Counter Measures during WWII.
In our days this trend proceeds with increasing speed. New developments aim for faster, less detectable, more manoeverable aircraft and are overall more and more equipped with electronic systems enabling the crew to fly and navigate under adverse weather conditions using automatic terrain following or terrain avoidance systems with navigation accuracies up to some meters using updating procedures, GPS or JTDS. The cost of the electric/electronic equipment more and more exceeds the pure aircraft costs.

Not only the bombs require a more sophisticated release system but also the addition of highly intelligent missiles add to the complexity of the overall Weapon Delivery System.

2. CURRENT STATUS OF WEAPON DELIVERY SYSTEMS

The weapon delivery system of a modern fighter aircraft consists mainly of the following subsystems: (see Fig. 2)

- Stores Management Systems (SMS)
- Gun Control System
- Missile Management System
- Interface Avionic/Computer/Displays and Controls

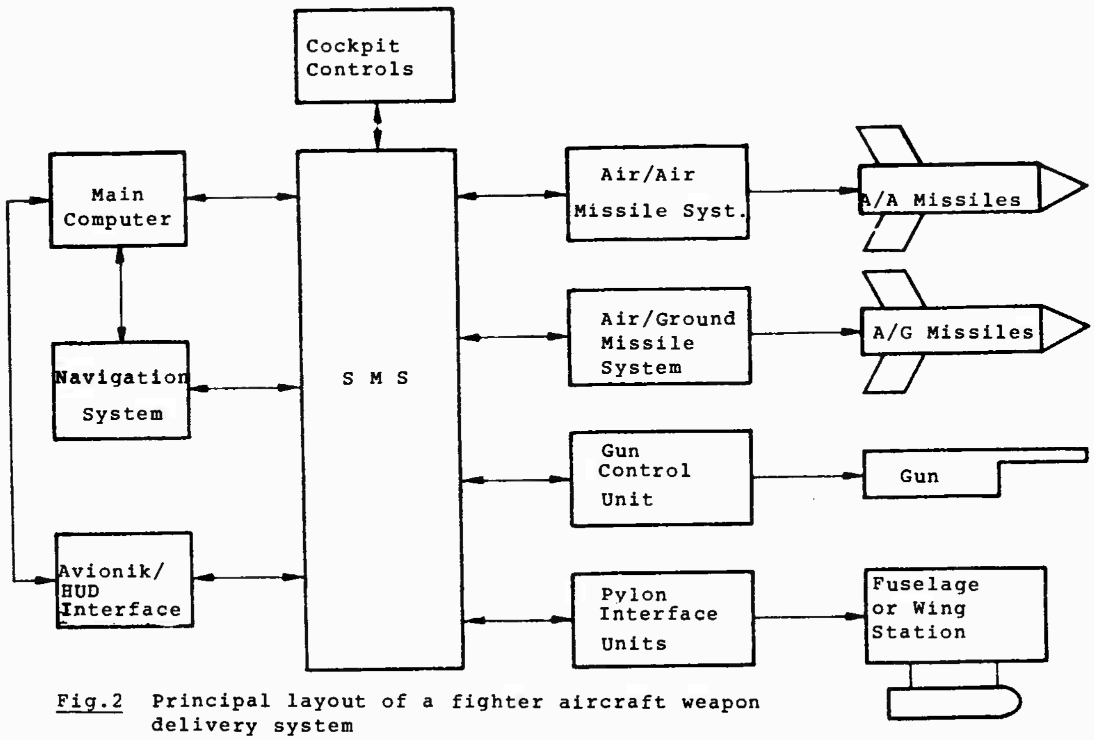


Fig.2 Principal layout of a fighter aircraft weapon delivery system

2.1 The SMS

Before take-off the ground crew has to program the available and loaded weapons into the SMS which is normally done through dedicated codes. Special self-testing circuits are checking whether the programmed load is compatible with the conditions on the closed bomb racks and whether the load is acceptable for reasons like loading symmetry or aerodynamic clearance.

Shortly before take-off the bomb racks are equipped with cartridges. Already now the crew can decide on different weapon packages for preplanned attacks to be stored in the SMS for immediate use. In an automatic release mode, this attack package information is sent to the Main Computer which in return produces release cues at the appropriate time intervals to give the required ground spacing.

The SMS will then distribute the release signals and initiate the release.

Beside this automatic mode the manual mode is maintained to be used depending on operational requirements or equipment failure.

An additional special mode for the SMS is the emergency jettison which cleares the aircraft from all external stores in the shortest possible time in cases of emergency.

Important design criteria for the SMS are:

- No unwanted fuzing or release of a weapon by defect of a single component.
- No inhibition of the emergency jettison function by defect of a single component.
- Only reduced but not inhibited operability of the system by defect of a single component.
- High flexibility for adaption of new weapon types.

2.2 The Gun System

Although a gun in a modern aircraft would appear to be an old fashioned relic,most fighter aircraft still carry gun systems for an air/ground role or for a short-range air/ air combat. The main differences to former times are the increased caliber, increased firing speed of several hundred rounds/minute and improved projectile velocities. Guns are still installed in modern aircraft because of several advantages over A/A missiles:

- also useable for short range combat ("dead area" for missiles)
- aircraft with guns is still armed although all missiles have been fired
- comparing installation/ammunition costs for guns with missiles, guns are very cost effective
- guns are also useable against ground targets

The gun System is controlled and preselected via the SMS through a Gun Control Unit. In a two-man cockpit,usually the pilot is in control over this system,using direct visual contact and the HUD.

2.3 The Missile Management System (MMS)

An increasing important role for the overall weapon system is taken by the MMS. It nowadays consists of several units dedicated to the special missiles.

2.3.1 Air/Air Missiles

Air/Air missiles are usually controlled by the pilot. The pilot activates the missiles seeker head (either Radar or I/R), waits for a lock-on information (audio tone or HUD aiming) and fires the missile, activated through the SMS and the Air/Air Missile Unit.

2.3.2 Air/Ground Missiles

Air/Ground or Air/Ship missiles are usually used in preplanned attacks and mostly controlled by the navigator in a two-man cockpit,because of the complex nature of weapon aiming, arming and navigation. Seeker heads may be controlled by TV, I/R, Laser, Radar homing, or active Radar. The actual firing is initiated through the SMS and the relevant missile interface unit.

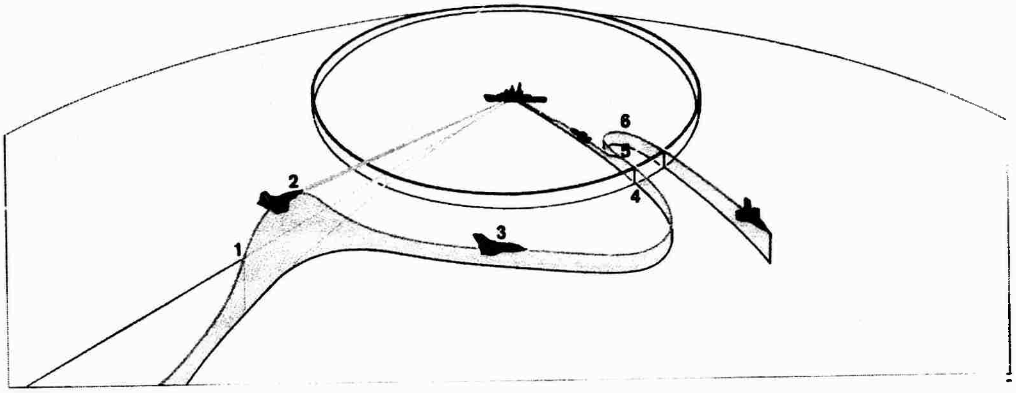
A/G missiles with TV or I/R seeker head (i. e. Maverick) can be controlled from the aircraft normally only during the aiming phase. When a target lock-on has been achieved (shown i. e. on a TV monitor), the missile is beeing fired and keeps the target picture as accurate as the crew was able to insert during the lock-on phase (fire-and-forget missile).

Characteristic points: Distance to target relatively small (high risk), not useable in bad weather conditions, for Laser guided missiles a separate Laser designator is neccessary, aircraft break-away after firing.

A/G missiles with Radar homing devices are used as a counter measure against hostile Radars. Presently these missiles are more adapted for use against preplanned targets. They approach the target with high speed to avoid the detected Radar being switched off again. There is also a possibility for a usage where the missile is launched into the expected area and is then waiting on a parachute for the hostile Radar to be switched on.

A/G missiles with active Radar head (i. e. Exocet, Kormoran) get their target information from the aircraft Radar already far outside the missile firing range (see Fig. 2) and the Ground/Ship defence distance. The aircraft then can approach the target from a different direction under the Radar horizon and is then either firing the missile within its range without any further updating (lower hit probability), or is very shortly coming over the Radar horizon for a data update before firing. In both cases the aircraft is still outside the ground/ship defence area during its break-away and escape manoever. The missile itself is flying as low as possible and only initiating its active Radar shortly before reaching the target for final target aiming (especially for moving targets.

Characteristic points: High hit probability, low risk, useable under all weather conditions, aircraft break-away after firing



1 Aircraft rises above radar horizon of the target
2 Input of target into the navigation system of the aircraft
3 Approach from below radar horizon
4 Maximum mission range
5 Launch
6 Fire and forget

Fig. 3: Typical technology progress

3. PREDICATED TECHNOLOGY PROGRESS

The coming years will bring a continuing progress in all aspects of technology. Fig. 4 shows the development progress in view of data processing problems.

Components	MSI (20-50 Gates)	LSI (1000 Gates)	VHSIC (100 000 Gates)
Working Memory Access Time	Magnet 1 µsec	Semiconductor (CMOS) 0.25 µsec	Semiconductor < 0.05 µsec
Memory	Drum	Disc, Bubble	optical
Computer Operations	0.35 MOPS	> 1 MOPS	> 50 MOPS
Data Transmission	< 100 KHz	1 MHz (MIL-Bus)	50 MHz + Fibre Optics
Program Language	Assembler Fortran IV	C/Pascal	ADA
	1970	1980	1990

Fig. 4: Technology Progress in Data Processing

The technology progress in all ECM matters (see Fig. 5) is strongly linked to the weapon aspects. This link will get stronger in future when direct connections exist between the ECM system, the Main Computer and the Weapon Control System.

	1970	1980	1990
Transmitter	MAGNETRON	TWT	SOLID STATE
Receiver	CRYSTAL	SUPERHET	BRAGG-cell
Frequency		J-BAND	K-BAND
E/O Receiver	IR	+ LASER	+ CCD's
Antennas	OMNIDIRECTIONAL	PHASED ARRAY/ADAPTIVE ARRAYS	
Bearing Accuracy	(10°)	(5°)	(1°)

Fig. 5: Technology Progress ECM

All the above predictions are influencing the planned concepts for future aircraft and also the necessary effort for starting a development or integration test programme.

4. DEVELOPMENT OF AN INTEGRATED WEAPON DELIVERY SYSTEM

In former times WW 1 weapons were carried on an aircraft by adaption, no special measures were taken during aircraft development to optimize the interface to the weapons or to make the weapon delivery more efficient. This view has changed considerably and nowadays the planning effort for the weapon delivery system (WDS) already starts during the development phase of the aircraft. All components of the WDS have to follow defined rules in terms of qualification requirement, standardized data transmission links, cable connectors or others. Equipment and subsystem development is controlled to follow the above rules and finally leads to an integrated rig test facility where all the requirements can be checked under simulated conditions up to a stage where the WDS for the first time is fully operable in the prototype aircraft.
Very often it is not a complete new system or aircraft to be developed but only parts of it. The principle idea is still that already the development of the equipment should be controlled (or very well defined) to enable an optimal adaption of the single equipment into the WDS.
An example of such an integration and test facility is shown in Fig. 6.

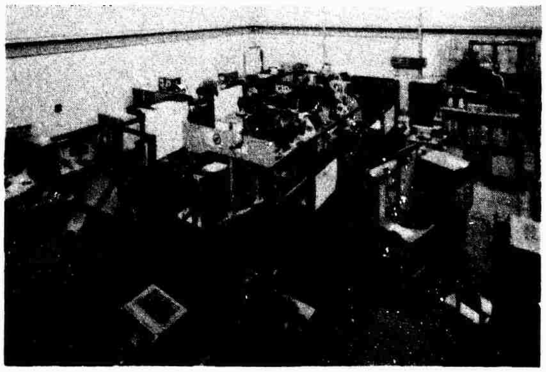


Fig. 6: Rig facility for integration and test

5. CONCEPT FOR A FUTURE WEAPON DELIVERY SYSTEM

As shown in Fig. 4 and 5 future WDSs will be strongly influenced by the general technology progress. Fig. 7 summarizes some aspects of progress in this area.

Built- in Test Maintenance by	10 % External Tests	90 % I-BITE	100 % Automatic Maintenance Prediction
Navigation		Inertial Navigator	GPS/ITDS/Strap Down System
Equipment Software	Fixed Program (PROMs)	EPROMS	Free programmable (ADA)
Store interface	Different for each store	Some standardized	Mostly standardized (MIL-1760)
Signal distribution	Signal lines	MIL-Bus1553 B	Optical Bus
ECM interface	Passive indication and active Countermeasure separated	Passive indication half-automatic connected to active ECM	Passive indication automaticly connected to active ECM, halfautomatic to Chaff/Flares and ARMs.
Penetration Aid	Manual TF	Automatic TF	Automatic TA
Air/Air Radar range Air/Ground Missile stand-off range	~30 km ~10 km	>50 km >30 km	>100 km >100 km
	1970	1980	1990

Fig. 7: Aspects in Weapons's Control equipment progress

5.1 Intelligence Distribution

Already in the planning phase of a new weapon system a decision has to be taken whether to put more intelligence into the weapon carrier (aircraft) or in the weapons themselves. There is a tendency to put more intelligence into the weapons but obviously there is an optimum between carrier and weapon intelligence considering mission success, financial effort and vulnerability risk. Without having an highly intelligent carrier, the target area will only be reached with higher risk and the information given to the missiles will not be sufficiently accurate. On the other hand a very intelligent weapon is necessary to increase the stand-off range (reduced risk) and the hit probability.

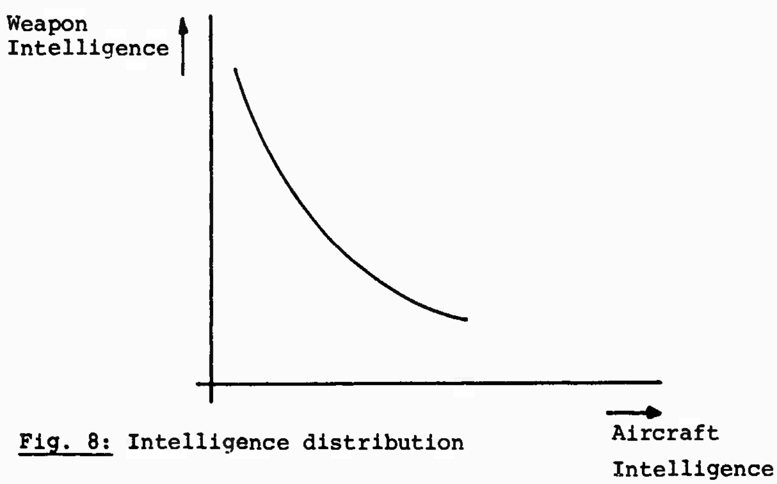


Fig. 8: Intelligence distribution

Several facts should be considered in context with above graph:

- The higher the weapons intelligence, the less the carrier's intelligence required.
- The higher the risk for the aircraft, the more capabilities (range, intelligence) are required from the weapon.
- With increasing aircraft intelligence the necessary weapons intelligence is lower (for comparable mission success) but to minimize the risk it should be as high as possible.

6. CONCLUSIONS

The principal layout of a fighter aircraft WDS (Fig. 2) does not change very much when using future technologies. The great changes are in the details. The cockpit controls are concentrated to form a Multifunction Keyboard, Main Computer and Missile Computer are free programmable, the Avionic Interface with its sensors (i. e. Radar) provides an extended range for target acquisition. The weapons themselves have more and more intelligence, a longer range, quicker reaction times, are less sensitive against external ECM and can directly be adapted via a standardized mechanic and electric interface including a MIL-Bus 1553 B. Because of the concentration of control elements and the higher intelligence,the workload on th crew is getting smaller enabling single seater aircraft without loosing combat effeciency.

Laser weapons, although already in development in greater aircraft and spacecraft, are not considered in this paper, because with the existing or predicted technologies they can not be used in fighter aircraft for a considerable time coming. They could however strongly influence the overall situation, especially when great effective space-based Laser battle stations would be available to be used against all kinds of missiles and aircraft.

CADAS - A Computer Aided Design Tool for Avionic Systems

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Summary

The ever increasing cost of test software, both in real terms and in relation to target software cost, is posing a severe burden on the development of embedded systems. The comparative, short life span of an avionics package in comparison to that of the airframe further emphasises the need for a cost effective test tool. This

~~The~~ paper outlines the development of CADAS - a computer aided design tool for avionic systems. ~~Prior to outlining the basic concepts behind CADAS~~, an overview of present methods for validating software is presented first. The basic concepts behind CADAS

These concepts are then expanded to illustrate how certain key elements, such as the events language, the automatic generation and inclusion of models, etc. have been implemented.

In conclusion the paper reports on the usage and achievements todate and outlines ~~the~~ objectives still to be achieved. Finally the case for including such a general tool as a basic component of the programming support environment for embedded software is presented.

1.0 An Overview of CADAS

1.1 Primary design aim

Over the past decade, test support software, whilst usually constituting a "by product" of an avionic development program has generally accounted for an increasing "bleed off" of available project funds. This development when combined with the rising cost of identifying a software system design error or worse still a program error at final hardware-software integration or even during flight trials, has resulted in many projects experiencing a cost explosion.

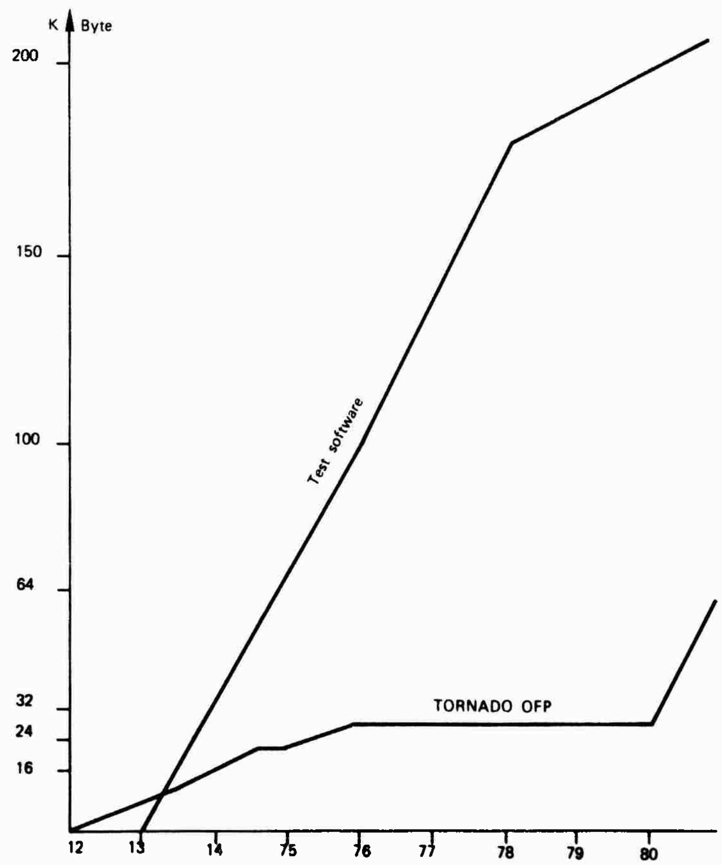

Figure 1 Comparison between the growth of Tornado OFP software and the required test software

The prime aim therefore of CADAS was to provide a cost effective closed loop dynamic evaluation/development tool which could be used at the earliest possible stage in the development stage of the system life cycle. Since CADAS may be used by all component manufacturers, reliable read across of tests may be achieved. This will help reduce integration problems and permit the final integration rig to concentrate more on the assessment of the overall system performance.

1.2 Primary design features

Of all the required features minimal maintenance and a user friendly interface were considered to be of prime importance. The former was achieved by high modularity and the implementation of the software in a high order language (HOL). The implementation of the system as a multi-task not only served to emphasize the former but easily permits the system to be downloaded into a multiprocessor system.

The software has primarily been written in Fortran (90%). The remaining 10% being written in assembler, due to hardware interface restrictions such as A/D converters, real time keyboard and D/A converters.

In order to minimise user input errors, the user interface is primarily via menus. Where text input is required, it has been optimized to improve fault tolerance. Questions which have become redundant due to previous answers are not presented to the user. He is always prompted for data in a positive format, that is the nature of the awaited reply is defined. In the trivial case, the user will be informed that a "Y" or a "N" is required, however where character strings must be defined, for example in the case of present position, the user is presented with a mask to aid him in the formatting of the input. However should the user give an invalid reply, or respond with a question mark, he is presented with the appropriate text from the users manual.

In order to support test activities, the system is built around a data base. A key feature of the data base management system is the capability given to the user to define which models or actual hardware units he wishes to activate for a given test. However should a model not be available from the libraries within the data base, it may be automatically generated and inserted.

As a final design consideration it was predefined that the system should run on commercial OEM available hardware.

1.3 Computer aided design tool versus test tool

A good software development and maintenance philosophy stresses the need for demonstrating the compliance of the product with the specification at each stage of its life-cycle. It is therefore highly desirable to be able to apply the same tool in all phases of the software life cycle (1). Unfortunately, most software tools have centered around the detail design and validation phases. The tools available have tended to reflect that they were written for a particular end user and as such provide very little on-line help. They therefore can not be justifiably defined as a CAD.

An ideal tool should support the user to perform the following activities, independent of which project is under investigation.
- generate the required test environments from the system requirements
- provide instrumentation of the target software
- automatic execution and validation of the target software
- evaluate data and update test coverage report
- localise and identify errors in target software
- ease design and development of "exception handlers"
- provide trace back and cataloguing of previous tests.

In order to provide these facilities with adequate on-line help, the tool needs to be conceived as a CAD tool as opposed to just a test tool.

2.0 Present simulation and test tools

2.1 Nature of present test systems

Test systems may be subdivided into two categories based upon the environment generating processor(s), that is:

i) systems which are supported by specialised, and therefore expensive, non OEM hardware, for example specific test rigs make use of extensive dual ported memory and hardwire features
ii) standard OEM processors tailored to the test tool role by means of their software.

The former will not be considered here, as its cost is prohibitive for general use and its disadvantages are well known.

Most test tools of the second category originated from the desire to posess a good data acquisition capability. The various signals from the avionic equipments were to be generated by providing a means of stimulating the actual equipment. The rig therefore by definition was not only project specific, it was also version specific. Unfortunately the response from some of the stimulated equipments such as the inertia navigation platform were too slow to be of any use. A possible solution was not to stimulate the IN but to mount it on a six degrees of freedom turn table and generate signals to drive the turn table. However, the provision of the latter is not cost effective in implementation except for the final system integration rig. In general the stimulation of equipments in order to provide a realistic environment for the development of the avionics software may be summarised as follows:-

1. not satisfactory as some equipments were unable to respond satisfactory
2. too costly and version specific
3. unable to generate controlled errors
4. unable to analyse equipment signals on line in a suitable manner for the software systems engineer
5. problematic from a logistic point of view.
6. configuration maintenance problems.

It became clear that for software development, a better and in some cases the only solution was to simulate the appropriate equipments as opposed to stimulating them. Unfortunately the test tools had been developed only with the data acquisition requirement in mind. Partly due to hardware and software limitations, the models which were to run in real time were often programmed in assembler.

2.2 Simulation techniques

Whilst the time slice per cycle and the available memory to a large extent dictated the level of complexity or simplicity of a model, the difficulty of defining models in assembler served only to simplify them further.

The advent of faster processors and cheaper memories combined with the development of compilers optimised from a run time code point of view has enabled real time models to be written in HOLS.

The inherent restrictions and difficulties of using assembler language for simulation purposes have long been recognised. Many programmers indeed would even argue that commonly used HOLS are not suitable either for such purposes, and as a result such languages as SIMULA and DSL77 have been developed. Whilst the latter provide a very friendly interface to the user for describing complex simulations, the resulting models may be very complex and may only run in simulation as opposed to real time.

The depth to which a piece of equipment is simulated will reflect the extent of software and hence cycle time required. Fortunately in order to validate or test a software package only a subset of the total functions of a given equipment are normally required. Therefore the performance envelope of the equipment may be covered by a summation of the individual performance envelopes of the various models. This concept, of course, is not new, however in general no relational control between the various versions had been embedded in control software, but relied upon the user, at worst, to bury the appropriate models in code, compile and task build prior to test run. This procedure from the QA point of view of course was unsatisfactory since the test tool after change was invalidated. CADAS has provided this means of relational control between the various models.

2.3 Event languages

An event may be defined as the change of state of at least one signal within the input/output area of the test tool. This signal may either be a test control parameter of the test system for example to switch on recording, or may constitute an input to the target software. A formal means of predefining these changes in relation to test time is provided via an event language.

These event definitions may be invoked to achieve either or all of the following results:-

i) to generate an automatic repeatable test
ii) to provide a means of dynamically switching values either at a frequency or at a given time that would be difficult to achieve via a human input.
iii) Where the change of certain variables does not warrant the production of a model

Present event languages may be classified as one of the following

1. Open loop and too simple an instruction set eg ATESP
2. Oriented towards computer scientists as opposed to software engineers eg SOFTEST
3. Hardware orientated and difficult to apply to task of testing embedded software eg ATLAS.

In order to ease the user interface an 'ADA like' events language is under development for CADAS. This is an attempt to provide a sophisticated event language providing such features as looping, on line calculated comparisons etc, which will have the same grammar and syntax as the language that the user will probably be programming his software in. The resultant test file should be more readable and comprehensible to such authorities as QA and project management than previous event languages.

2.4 Developments in software validation techniques

There are at present, three popular methods available to the software engineer by which he may establish if the requirements are met:

1) program testing (2)
2) program proving (3)
3) symbolic execution (4)

Program proving and symbolic execution techniques require that the intended behaviour of the target software be defined using a set of assertions, which in turn are used to prove mathematical theorems about the target program. Unfortunately proof techniques tend to be 'effort intensive' and do not lend themselves easily to proving parallel programs. The latter, is of course, a characteristic of embedded avionic software.

Testing in one form or another is the most widely used of the three techniques. Unfortunately, in order to prove a software module to be correct an inordinate amount of testing is required. Since input domains are frequently large, test data sets may only address a subset of the input values and are usually only used in "open loop" testing. The automatic generation of test data is the aim of many test systems under development.

Current research test systems such as RXVP (5), SADAT (6), FACES (7), DAVE (8) and SQLAB (9) emphasise the importance of measuring test coverage at the expense of validating the test results. In general they generate test data via a control flow analysis of the target software, ie branch and path testing as opposed to an analysis of the data inputs and outputs, i.e. cause and effect testing (10) (11). As a result the nett effect is that the program is tested against itself by deriving the test cases from a static analysis of the program structure and the test coverage is measured via a dynamic analysis of the test paths (1). This although a useful tool during program development can not be considered as a system validation aid.

Satisfactory software validation can only he achieved if the required test data sets are generated from the requirements. CADAS does not set out to define groups of data sets but attempts to embody the requirements in a set of models. These models will then generate the appropriate test data in real time to correspond to the present situation in the performance envelopes of the respective models.

3.0 CADAS General concepts and philosophy

3.1 Definition of test environment

The effect of defining groups of test data sets or of activating particular models is to define the required environment in which the target software is to be tested.

However in general the operational envelope of a given target system is too large to be efficiently defined by a single test environment. CADAS permits the user to easily define a set of test environments, the sum of these will define the maximum possible scope of the test coverage. These test environments, as opposed to data sets are not point definitions, but define a subset of the total environment envelope. The definition of this environment is known as the preparation mode.
The user having defined his environment, then goes on to define the test start conditions via the initialisation mode. Having satisfactorly completed this action, the user may explore the defined environment to his own satisfaction. He cannot however, migrate from one to another during a test.

3.2 Application Scenario

Due to contractual problems, project size components for embedded systems tend to be developed in parallel and at different centres. The absence of a common test system across the field of activity complicates the problems associated with integration. It is therefore intended that CADAS should be capable of providing a unified environment at all the centres of development and should be usable by all personnel irrespective of their academic discipline, or project responsibility.
Therefore the cryptic type of test data definition by means of assertions has been avoided.

3.3 Use of CADAS at system requirement level

In recent years much attention has been given to the development of requirement and specification languages. With the aid of such tools it is possible to formally define specifications and check for omissions and conflicts. However, they do not prove that the design requirements are realistically achieved and in a cost effective manner. Simulation techniques are being used to establish product feasibility. However the software models developed for this phase are not always carried across to the other life cycle phases. CADAS will provide the capability to generate models from the requirements via an interactive procedure. These models in turn will represent the test data by which the software may be tested. By this mechanism CADAS meets the need to generate "testdata independent of the program specification" (1)

As a project advances the specifications of the equipments can be updated and new model versions generated.

4.0 CADAS IN MORE DETAIL

4.1 General Structure

CADAS has been designed as a multi task/multi processor/multi user system. User inputs have been minimised, however where large character string inputs are unavoidable, for instance in the case of the event language, use has been made of screen format masks.

Particular activities such as test preparation are defined as modes. Each mode is composed of at least one task but may be more (e.g the real time run mode is at least 7 tasks).

Upon entering the test system, the user is first requested to define, via a menu, which software system he wishes to test. This enables the appropriate data to be retrieved from the data base. Control is then passed to the moding executive.

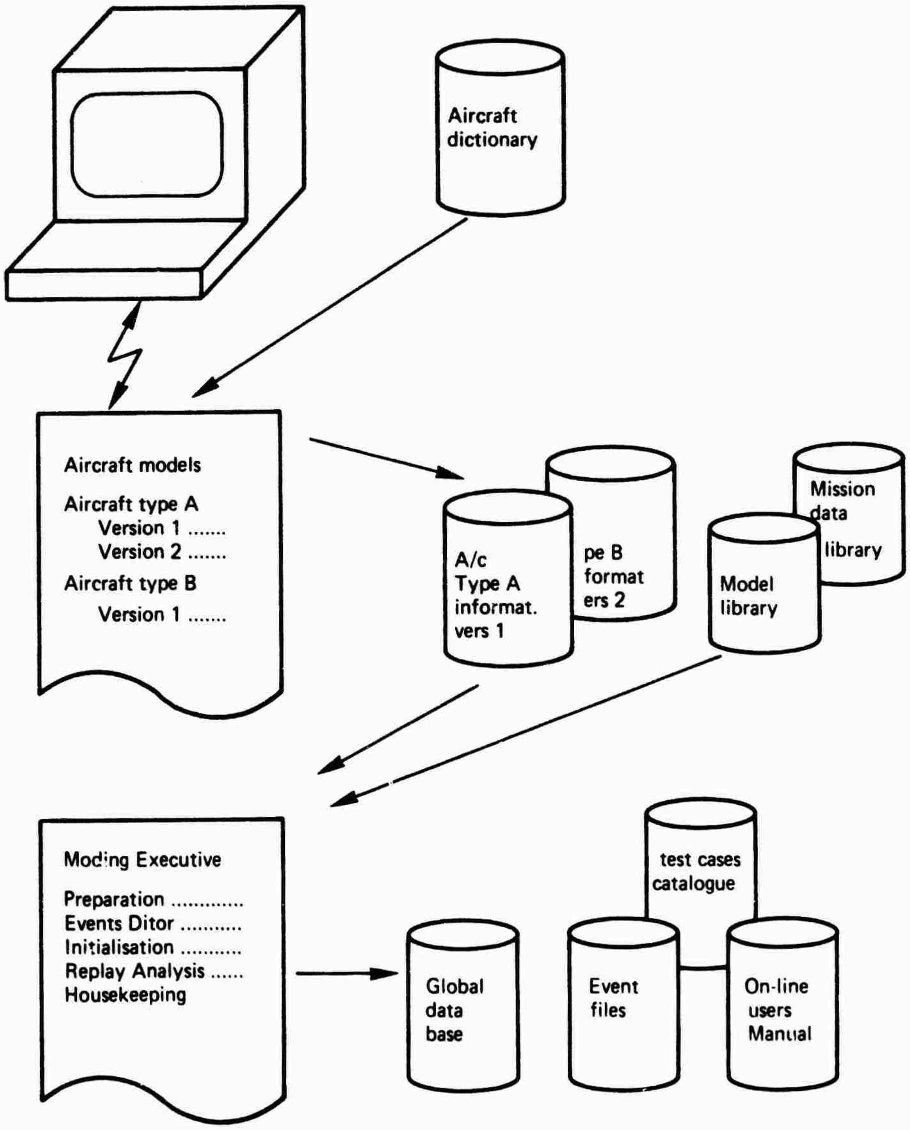

Figure 2 System, envirement and data selection

Control from one mode to another is always via the moding executive with the exception of the runtime mode, whilst data exchange from one mode to another is via the data base.

The termination of an activity in a given mode results in the user being passed automatically back to the moding executive. The user then defines his next activity or desire to exit via the moding executive menu. The user can only enter the real time run mode via the initialisation mode. This exception is felt necessary in order to guarantee that all the required data and hardware units have been correctly initialised. In all modes, except the real time run the system is in multi user mode.

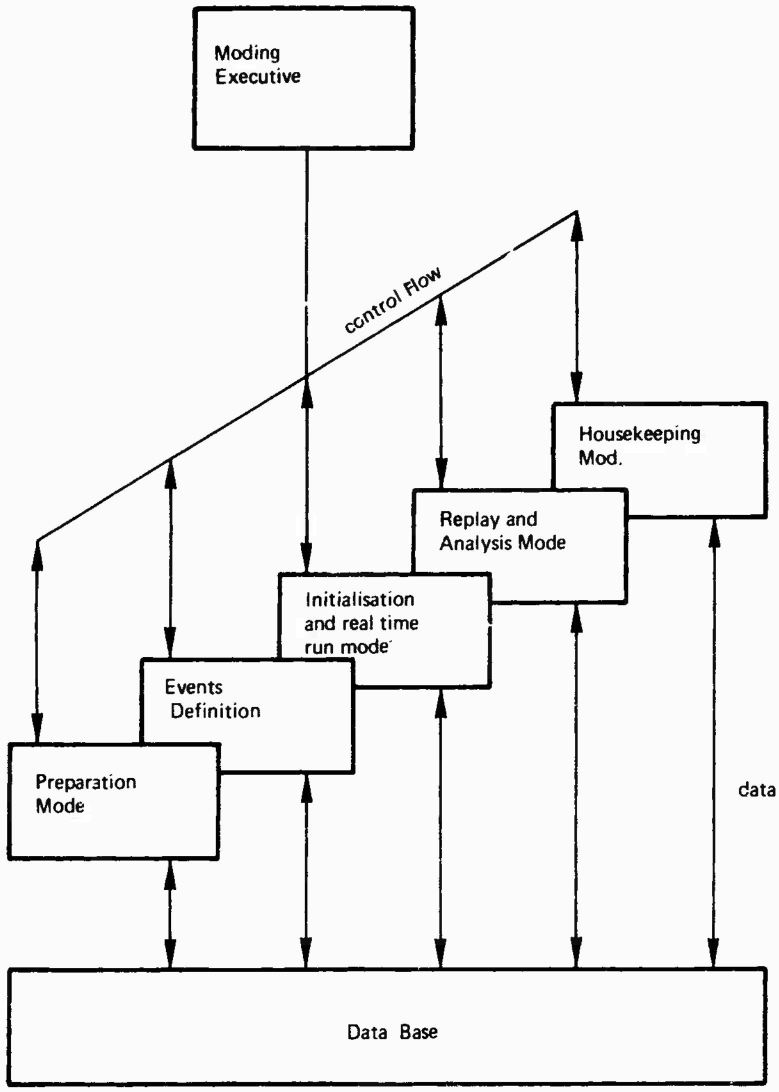

Figure 3 Data and control flow on CADAS

When in the initialisation mode is reached, i.e. just prior to entering the real time run, the required facilities become reserved and the appropriate components of the multi processor system revert to single user capability. Of course, if the system is running on a single processor configuration, than all other users are logged out of the system in a orderly manner. This avoids having under utilised hardware.

4.2 Test Preparation Mode

Its purpose is solely to define the required test environment, by means of the following five features:

a) a unique test name
b) model selections
c) 'on-line' display selections
d) automatic events selection
e) recording requirements e.g. definition of switches etc.

The simulation axis may be further divided into the following elements

i) environmental, e.g. weather, terrain
ii) instrumentation, e.g. positional sensors, command sensors
iii) target software, e.g. simulation modules of program requirements
iv) platform, e.g. aircraft (type and version)
v) platform control, e.g. joystick
vi) facility control, e.g. SMS
vii) associate equipment, e.g. weapons
viii) point of interest, e.g. targets

During the preparation mode interlocks are provided in order to ensure that no incompatible models are selected or that no redundant questions are presented to the user.

Most tests will not require very detailed models for all equipments, but will require an emphasis to be placed only on a subset. For example, in order to test a weapon delivery package, detailed models of Laser and GMR will be required (whilst navigational equipment models such as SAHR, radar altimeter may be relatively primative). The preparation mode allows such a model mix to be defined, thereby permitting the test system to be tuned so that the desired specific attribute may be highlighted.

The end product of the preparation mode is a catalogued file which contains the defined parameters for the test. The task of preparing tests is totally independent of all other modes and as a result the user may define as many preparations as he wishes at one or more sittings.

4.3 Events Editor and Language

An event is defined as the change of state of at least one signal within the global data area of CADAS. This signal may be part of the test data or may be a CADAS control variable, such as freeze test activity.

A closed loop 'ADA looking' events langugage is under development. In order to support this feature a user friendly editor, which allows the user to create his files in a simple and controlled manner, (each event is syntax checked on line) has been developed.

It has been established that the syntax and grammar of ADA are more than adequate to define typically required events.

```
With FLTPRO use MISSION 1
                reset CLOCK;
                press PLN on TV/TAB_2;
        after 2 SECS
                press NAV on TV/TAB_1;
        after 2 SECS
                press KEY_3 on TV/TAB_1;
                press MAIN on NMCP;
                press AUTO on NMCP;
                engage BHH_MODE on AUTOPILOT;
        if WAYPOINT_A is OVERFLOWN then
                goto LABEL;
        endif;
        after 2 SECS
                press IN on NMCP;
                disengage AUTOPILOT;
                perform A HIGH LOFT;
        EVENTS inhibit;
« LABEL »  after 1 SECS
        while RANGE from AIRCRAFT-POSITION to WAYPOINT_B> 20 NM then loop
                 null;

        end loop;
        start RECORDING;
```

Fig. 4 Example of CADAS Event Language

The philosophy behind the implementation of the language has been similar to those of SNOBOL 4. That is the initial commands are translated into a set of macro assembly instructions, which in turn are then compiled to produce object code.
The translation is a two phase process, the first phase translates the lexical text into a series of dictionary entry codes. Upon definition by the user on which machine the events will run during the test, the appropriate sections of the events dictionary are accessed to create the required macro instructions. After compilation the task builder/ linker instructions are removed.

During the real time execution the events are read into a reserved buffer in memory, entry to which is controlled by a server routine.

A typical area of application for such a feature in the future would be for the design and validation of "exception handlers".

The concept of exception handlers has been received with mixed feelings:-

"and some of them, like exception handling, even dangerous. We relive the history of the motor car. Gadgets and glitter prevail over fundamental concerns of safety and economy" (12).

"It is clear that the use of an exception provides the better structured program" (13).

"ADA is designed to permit defensive or fault-tolerant programming. This is in contrast with traditional styles of programming, in which there is an implicit assumption that everything is correct" (14).

An analogy may be drawn between the acknowledgement that embedded systems may not be reliably declared as perfect and the development of Fracture mechanics in the 50's. Without the development of the latter, the use of light alloys in safety critical areas would be severely limited.

"Exceptions should be used for rarely occurring cases or those which are inconvenient to test for at their point of occurrence" (10). They should certainly not be used in the form of a generalised 'catch all' mechanism, but rather for the systematic step by step identification, evaluation and subsequent removal of "grey areas" during system development as well as their containment in service. The nett effect of this should be to lead to a better fault tolerant system.

With the help of CADAS it should be just as easy to exercise and validate exception handlers as it is to define them. By permitting the designer to define the details of his required handlers externally, that is via the event language, time to develop and validate will be minimised. Configuration control improved and interface problems with other designers/programmers will be reduced.

Once the details are frozen, the fact that the lexical construction is already ADA compatible, will permit its automatic migration into the target system.

4.4 Initialisation and Realtime Run
This mode allows the user to predefine his initial start point in the predefined environment. Interlocks are provided between this mode and that of preparation to ensure that the user may only initialise the relevant variables. Prior to the real time run, an active timing check is made to establish the cycle load of the simulation. During the real time run the user may activate/suspend activities, such as events or recording. He is further provided with an on-line display of variables, the units of which may be changed at any time, input/output channels may be disabled/enabled from the display monitor and the test itself may be frozen to allow the user to examine any element of his data area.

The capability for 'on-line' analysis is an important aid in reducing the data saturation which normally accompanies a test run. For many tests it is sufficient just to be able to demonstrate that certain discretes are generated or particular bit patterns set. The 'on-line' monitor permits this to be achieved without the penalty of having to perform an inordinate amount of post test data reduction.

After completion or termination of the test whilst in the initialisation and real time mode the user may opt to reinitialise the same environment, or to leave the mode and formally reenter. The latter enables him to define another environment.

The ability to reinitialise the same environment within the initialisation mode has a dramatic effect on the rig usage efficiency of the system. All the real time tables and hardware initialisation requirements are still valid and therefore the user needs only to define the initial aircraft attitude positional data. This has the nett effect that a turn round time between tests is reduced by a factor of four to five.

On completion of the real time run the user is supplied with a report detailing which test conditions/assertions were not met, and the recorded observations of the defined software instrumentation.

4.5 Replay and Analysis
Having defined which test results he wishes to analyse, the user is provided with a test report in graphic and written form. The recorded data may be replayed at varying speeds. Using the software requirement models, the recorded data may be used to reconstitute internal signals in order to help fault identification. The user also has the possibility of using the test data to generate an events file, thereby enabling a manual test to be repeated.

4.6 Housekeeping Mode
This mode provides the user with the capability to perform such actions as:-

1) Test case and result traceback
2) Update of data base
3) Automatic insertion of new model
4) Amend appropriate dictionaries

The most important feature of the four is the ability to generate and insert new models automatically. The model is initially defined using the specification language EPOS. Using the decomposition feature it is possible to define in detail the required algorithms and the parameter names to be used. Once it has been established that the specification contains no conflicts or omissions, the data file will be accessed and the contents translated into a CADAS compatible model.
At present such a transformation is only possible into PEARL programs. It has been demonstrated that if a model complies with a predefined structure, it may be automatically inserted into CADAS. From work carried out todate, it would appear that this structure is applicable to all models.

Following QA acceptance the model would then be inserted into the appropriate libraries automatically.

5.0 Trends in CADAS development

5.1 Realised capabilities of CADAS

The system as a prototype has been run on a PDP 11/60 and used to exercise not only the operational flight program but also the Build Test Program for the Tornado IDS aircraft. Open and closed loop tests have been carried out manually and automatically. Using the ability to simulate equipment errors with an undulating simulated terrain have enabled tests to be carried out that would be normally impossible with actual hardware equipments and would require extensive flight trials.

A worst case cycle loading of 83% has been measured in trials, however this was with a recording frequency of only 10 Hertz. A recording frequency of 50 Hertz is at least required. Therefore in order to develop CADAS further, the already designed capability of being supported by multi processors must be implemented and realised.

5.2 Apse's and all that

Whilst the accronym APSE is an ADA specific term, the engineering fundamentals which it embodies have to some extent long been recognised as essential for the development of an embedded system. APSE is an attempt to standardise the various components and their interaction with one another. Certain components of the APSE such as compilers, command language interpreters and data base management have received wide attention in contrast to design aids and verification tools. "Stoneman" acknowledges that "the testing phase of a project is often more expensive than development" (15) and goes on further to say that "in the past and in much of current practice, the concept of a support system is not much in evidence. The tools available are not well integrated, nor do they form a complete set".

Whilst it acknowledges that the provision of an environment simulator is of particular importance and that it may well require as much effort to design and build as a major component of the system under development, it accepts the concept that environment simulators must be project specific.

Clearly elements of the environment must be by definition project specific, however only elements need be, not the total simulator. An ideal general environment simulator, must provide the capability for the user to define his requirements, inform him on which elements need to be generated, and via an interactive definition mechanism, define and generate the missing elements.

The need for such a facility is not only justified within the context of multiple projects but also within the life cycle of an individual project. "Stoneman" clearly defines the development nature of a software project:-
"The envolving nature of the requirements, where an initial general specification is made more precise as the project proceeds. This produces rapid interactions between design and experiment" (15).

In order to allow the designer to rapid prototype and evaluate the proposed changes, he must have a flexible, easily reconfigured simulation environment. The extension of the mechanism which allows this flexibility within a project to that of flexibility between projects is a logical step.

Whilst such a tool cannot be classified as an APSE basic element since it will undoubtly build upon the data base and the command language. The cost and complexity would warrant that such a general test tool be included in the MAPSE. After all ADA and APSE's have been specifically developed with embedded systems in mind, and testing/validation is an important element of that activity.

CADAS has shown that it is possible to implement a test tool, which may not only be easily and automatically updated, but is not project specific. In order to comply fully with the spirit of "Stoneman" CADAS will need to be redesigned in ADA, but only as a long term aim. Stoneman acknowledges that initially elements may be included in an APSE which are not written in ADA, but their interface should at least conform to that of the KAPSE. Unfortunately, at the moment these interfaces are not yet defined.

5.3 Limitations and developments on CADAS

Whilst CADAS will aid and speed up the process of validating software systems, it must still be remembered that testing only shows the presence but not the absence of software errors. In the maintenance phase of large systems, it will always be necessary to isolate, identify and rectify errors. The capability to use a test tool without specialist knowledge, as is the case with CADAS, will play an important part in the success or otherwise of such tasks.

Present development work is centered around the following areas:-

1. Validating multi processor capability
2. completing the implementation of the ADA like event language
3. improving recording and replay capabilities
4. validating an EPOS interface concept.

5.4 Further areas of application for CADAS

Due to its capability to provide "hands on" real time simulation of a system, the application of CADAS is not just restricted to that of validating software packages, but may also be used to provide the end user with a cost effective systems trainer. Particularly in the avionics application it could be used as a crew procedure trainer.

At the other end of the system life cycle, the user could apply it to perform a comparison of proposed solutions for a given system, for example to graphic presentation of information in a cockpit.

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DESIGN AND VERIFICATION OF ELECTROMAGNETIC COMPATIBILITY IN AIRBORNE WEAPONS SYSTEMS

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ABSTRACT

To achieve electromagnetic compatibility (EMC) among the electric, electronic and electromechanical systems in a complex airborne weapons system, the coordination of many engineering disciplines is required from concept to delivery. Often the primary objectives of structural, mechanical and electrical design will be in direct conflict with good EMC practices. Interaction of the EMC organization with many diverse engineering groups which have a common organizational tie only at a high level, usually the Chief Engineer, requires a flexible management structure with hard line reporting within the EMC organization and soft line ties to the supported organizations.

The major milestones required to achieve an electromagnetically compatible system are:

- Planning for EMC control;
- Analysis to highlight potential problem areas;
- Engineering evaluation tests to prove design concepts;
- Qualification testing of subsystems/equipments;
- Safety-of-Flight testing on airplane to assure flight safety; and
- System level EMC testing where safety margin demonstrations may be required.

This paper discusses the steps required to accomplish the milestones listed above and to assure that the weapon system will have a high probability of passing the final system level electromagnetic compatibility demonstration.

INITIAL PLANNING

In order to achieve electromagnetic compatibility in the design of a new aircraft or a major modification to an existing aircraft, the EMC engineering group is probably required to interface with more engineering organizations than any other. Although the EMC effort is small compared with the total budget of a large program, the large amount of interdisciplinary coordination required makes it mandatory that the project manager put his EMC group in a place within his organization to give it maximum access to all other engineering disciplines. Major programs with which the author has been associated have employed organizational structures in which EMC is part of the project as shown in Figure 1 and where EMC is part of a Technical Staff which supports several engineering projects as shown in Figure 2.

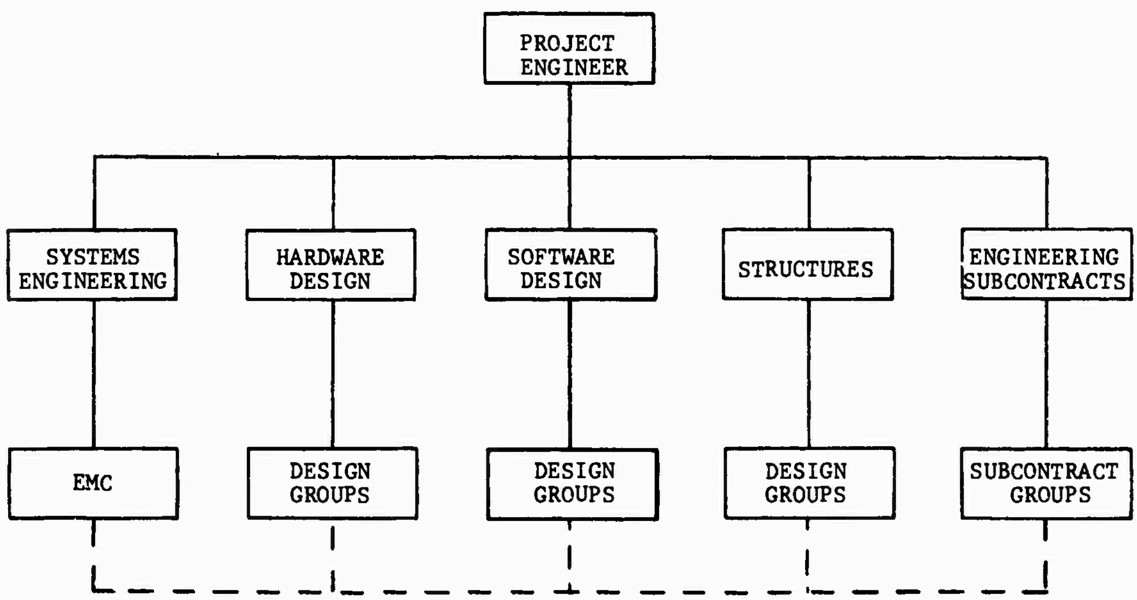

FIGURE 1

PROJECT ORIENTED EMC ORGANIZATION

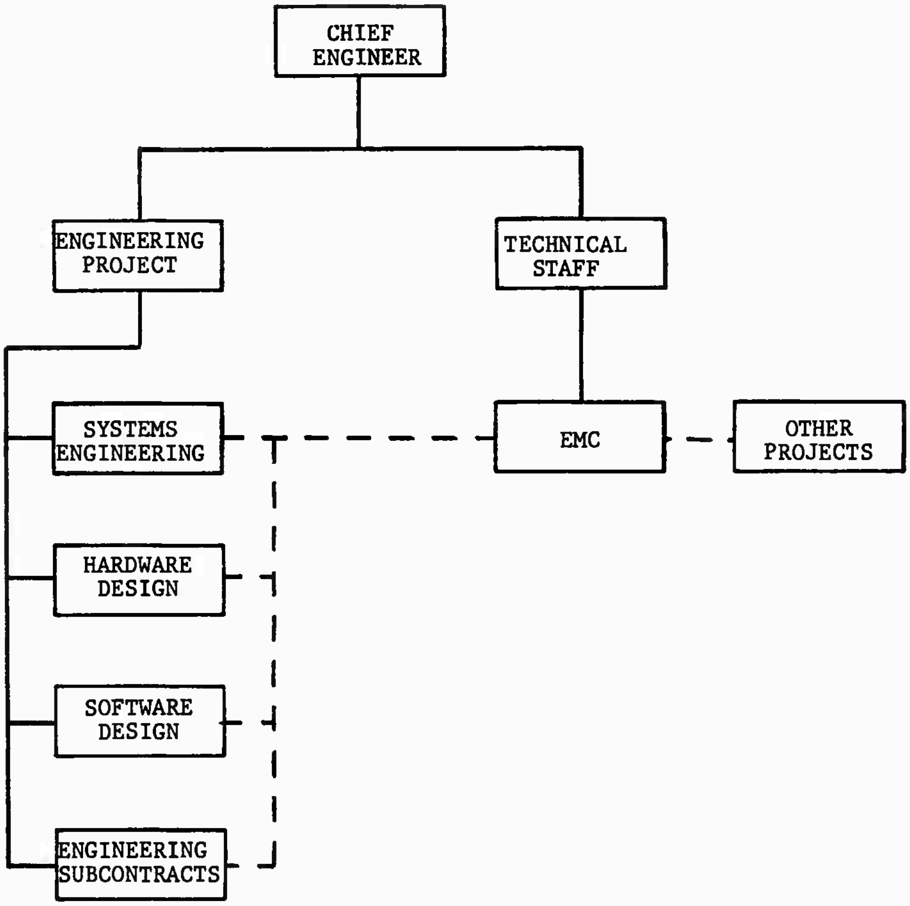

FIGURE 2

STAFF ORIENTED EMC ORGANIZATION

The success of each approach is dependent upon the size and number of projects being conducted simultaneously and to some extent upon the personalities of the individuals involved. The design and fabrication of a new military aircraft or a major aircraft modification would have a budget large enough to support an EMC group within the project's organizational structure. This approach has the advantage that the EMC team is dedicated to one program which eases the problem of assigning priorities among a number of programs. On the other hand, if large numbers of technical disciplines supporting the program are assigned to a central technical staff unit, coordination with these individuals might be more easily accomplished if the EMC group were part of the central technical staff.

In any event, wherever the project manager decides to put the EMC team, he should make the decision as early as possible and should make sure that the EMC group begin their interdisciplinary coordination soon. The amount of freedom that the EMC group should be given to perform coordination directly with other engineering groups without going through formal vertical management lines will depend on the initiative and competence of the lead EMC engineer and the amount of freedom to use his own judgment the project manager feels comfortable about giving him. Ideally, the EMC engineer would do the majority of his coordination with other groups through horizontal or "soft line" channels and use formal vertical communications channels mainly for reporting functions.

PRELIMINARY ANALYSIS

EMC requirements are traditionally written into contracts by referencing various specifications which prescribe subsystem/equipment level EMC design and test requirements and other specifications which prescribe EMC system level test requirements. Some U. S. Military standards and their NATO Standardization Agreement complements are shown in Table I.

U. S. STANDARD	NATO STANDARD
MIL-STD-461 Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference	STANAG 3516 Electromagnetic Compatibility of Aircraft Electrical and Electronic Equipment
MIL-STD-462 Electromagnetic Interference Characteristics, Measurement of	
MIL-E-6051 Electromagnetic Compatibility Requirements, Systems	STANAG 3416 Electromagnetic Compatibility of Aircraft Systems

TABLE I

COMPARISON OF U. S. AND NATO EMC STANDARDS

Specifications and standards are written to cover general cases and cannot possibly include the detailed information necessary to assure achieving electromagnetic compatibility at a reasonable cost for a particular design. This is why it is extremely important that an early preliminary analysis be performed and that the results of the analysis be compared to the standards and specifications referenced in the contract. Relatively large sums of money may be involved if requirements are left in the contract which are not actually necessary to achieve an electromagnetically compatible system and, as time passes, it is usually more and more difficult to get a change to the contract. Therefore, any change to contractual requirements should be defined as early as possible.

The manner in which the contractor plans to meet the electromagnetic compatibility requirements is contained in a document called an EMC Control Plan, which is normally required to be submitted 90 days after contract award. This plan will contain any tailoring to specification limits and any deviations to specified test procedures. After approval by the procuring activity, the EMC Control Plan becomes a contractual document. If any tailoring of specification limits or deviations to test procedures can be defined prior to publishing the EMC Control Plan, they should be incorporated into the Statement of Work or other top level contractual document at the earliest possible time. Since there may be several tiers of contractual documents from a top level Statement of Work down through specifications placed on suppliers, it is important that all of these contractual documents contain a consistent set of EMC requirements.

Some parameters which may have significant cost and schedule impact and which should be considered when tailoring specification limits and test procedures are:

- Radio Frequency Field Intensity Environment
- Acceptable Switching Transient Levels
- Electrical Power Quality
- Safety Margin Requirements

PITFALLS TO AVOID

Experience on a number of programs has shown that some potentially disastrous consequences can be avoided by taking some relatively simple precautions. A few of these experiences are listed below:

- The structures design groups may be unaware that structural design affects EMC and may not think to route the structural drawings through EMC for approval. Metal aircraft skin provides at least 20 decibels of shielding effectiveness. If the designer decides to use fiberglass or composite materials for some structural parts and there are sensitive electronic components within these areas, the result could be radio frequency interference which could be expensive to correct.

- Designers of servo systems with high frequency cutoff of a few hertz may not think to route their drawings through EMC because the response of their system is well below the frequency of any interference source generated on the airplane. In reality, operational amplifiers are good radio frequency detectors. Any modulation on the rectified radio frequency signal which is within the servo system's bandwidth will be seen by the system as a desired signal and it will pass through the system to the servo actuator as interference.

The above are just two examples of communications breakdown between design and EMC groups which can lead to catastrophic consequences. Designs which on the surface appear to be unrelated to EMC may in fact be profoundly affected. It cannot be stressed too firmly that the project manager should insist that the EMC engineer become familiar with the work of all design organizations, whether they appear to be related to EMC or not, and assess the designs for potential EMC impact. A little effort here early in the program will lessen the likelihood of problems arising later on.

HANDLING CONFLICTING REQUIREMENTS

There are cases where the best EMC design practices may cause undesirable side effects. Putting overall shields on cables decreases radio frequency coupling and thereby reduces the probability of interference to electronic circuits but it also increases cost and weight and makes them stiffer and harder to install. Adding excessive power line filters with capacitance to ground increases interference immunity but it also causes leakage currents to flow in the power lines. Certain types of electronic circuits are degraded by capacitance to ground whereas adding shielding on interconnecting cables to protect them from external radio frequency fields adds capacitance. To achieve compatibility, structural parts may be required to be electrically bonded whereas passivating techniques to reduce corrosion may insulate the parts.

Conflicting requirements such as those discussed above must be handled on an individual basis, ordinarily with some compromise to both EMC and system performance. The project manager should encourage compromises to be worked out at a lower level with the goal of achieving as little degradation to both system performance and EMC as possible. If this cannot be accomplished, the manager may have to make the ultimate decision as to what compromises are accepted. If this is the case, the manager should make sure that all alternative approaches are explained to him to aid him in making the final decision.

PREPARATION FOR TEST

Testing to verify that EMC requirements have been met usually consists of three types of tests. The first is conducted at the subsystem or equipment level in a shield room to verify compliance with component level requirements. Next the equipment is installed on the airplane and a safety-of-flight test is conducted on the ground prior to first flight to assure that systems required for flight are not adversely affected. Finally, when production hardware is available, a system level test is conducted on the airplane where all potential sources are exercised against all potential receptors.

Proper planning is essential if reasonable test schedules are to be met. Adequate time should be allowed to prepare test procedures and to design and construct any special instrumentation required. A test program requiring safety margin demonstration at the system level requires that approximately 18 months be allowed from program go ahead to final system level test.

Test procedures for the shield room test should include detailed steps for operating the equipment under test, the method used to determine if interference is present and precise pass fail criteria. The procedures should clearly state any tailoring to specification limits. For systems that are computer controlled, it is likely that special test software will have to be developed. Adequate time should be given to the software design group to produce the program and they should be given detailed test requirements so they will know what the software is required to do. Ordinarily the unit under test is housed in one shield room and test aids used to exercise the equipment are housed in an adjacent shield room. The test procedure should include detailed diagrams showing equipment locations and interconnecting wiring.

Safety-of-flight test procedures should contain detailed step-by-step procedures for operating the equipments required for test and pass fail criteria to be used for accepting or rejecting test results. Although not related directly to flight safety, it is good practice to monitor flight test instrumentation for interference to assure that data taken during subsequent test flights will not be perturbed by interference.

Planning for system level testing requires the longest lead time of the three types of EMC tests. MIL-E-6051 requires safety margin demonstrations of 6 decibels for electronic circuits and 20 decibels for explosive circuits when approved by the procuring activity where EMC problems could result in loss of life, loss of vehicle, mission abort, unacceptable reduction in system effectiveness, damage to vehicle or reduction in effectiveness that would endanger mission success. If safety margin demonstrations are required, an analysis must first be accomplished to identify the circuits that fall within the specified criteria. These will be determined by the criticality of function and circuit susceptibility. Thin film thermocouples attached to electro-explosive device (EED) bridgewires to measure heat rise have been successfully used for measuring safety margins of EEDs. A method of sensitizing digital circuits to demonstrate the required safety margin as shown in Figure 3.

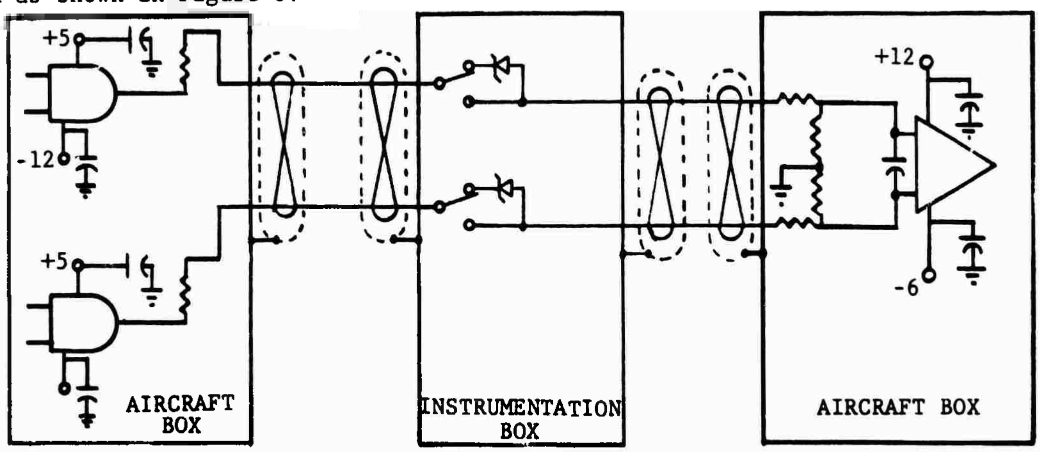

FIGURE 3
SENSITIZATION NETWORK FOR SAFETY MARGIN DEMONSTRATION

The diodes change the bias on the circuitry so that switching levels become more sensitive than normal. Diodes must be individually selected to achieve the level of sensitization required. A typical schedule for a system level test program with safety margin demonstrations is shown in Figure 4.

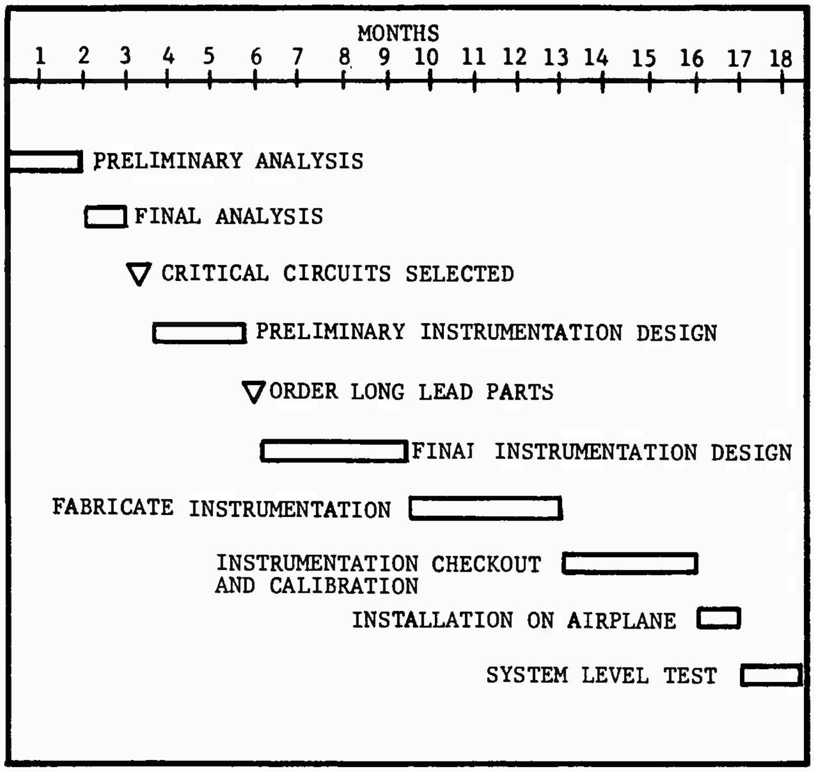

FIGURE 4

TYPICAL SCHEDULE FOR SYSTEM LEVEL EMC TEST
WITH SAFETY MARGIN DEMONSTRATION

Instrumentation used for safety margin demonstrations should be calibrated in the laboratory prior to installation on the airplane for the test.

TESTING

The ease with which testing can be accomplished will be determined to a great extent by the quality of the test procedures. The systems under test will be new and the operators will have limited experience in operating them so the test steps should be complete and unambiguous. Remember, it is much easier to figure out how a system should be operated when sitting at a desk in a warm office than it is when standing on a blustery flight line.

In conclusion, the success of an EMC program on a new airplane or major airplane modification is largely determined by the planning and analysis conducted in the early days of the program. If these have been properly executed, the testing should be a routine matter to confirm that the requirements have been met. It is hoped that this paper will be of help to those charged with planning and administering EMC programs.

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DISCUSSION

G.Hunt, UK

Is the type of avionic system described by Mr England in Paper No. 1, which utilizes commonality of data processing and transmission of raw sensor data, likely to provide particular EMC difficulties?

Author's Reply

I think not, especially if the data are transmitted digitally, which is the current trend. I have found that digital data transmission, if handled correctly is quite immune to interference effects. We have had some experience with Flight Test Instrumentation Systems which handle data essentially as Mr England proposed, which proved to be interference free.

D.Jaeger, Ge

What is your experience in using EMC-computer program instead of practical demonstrations of safety margins? For example, if you have calculated a safety margin of about 50 dB which may be expected, is it necessary to demonstrate > 6 dB by practical measurements?

Author's Reply

No. Our computer aided analysis program has proved to be at least 90% accurate. All errors so far have been in the safe direction. The analysis program has predicted some interference that did not occur but I have not seen an interference that was not predicted.

DESIGN, DEVELOPMENT, AND FLIGHT TEST OF A DEMONSTRATION ADVANCED AVIONICS SYSTEM

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SUMMARY

Ames Research Center initiated a program in 1975 to provide the critical information required for the design of integrated avionics suitable for general aviation. The program has emphasized the use of data busing, distributed microprocessors, shared electronic displays and data entry devices, and improved functional capability. Design considerations have included cost, reliability, maintainability, and modularity. As a final step, a demonstration advanced avionics system (DAAS) was designed, built, and flight tested in a Cessna 402, twin-engine, general-aviation aircraft. ~~The purpose of~~ this paper ~~is to~~ provides a functional description of the DAAS, including a description of the system architecture, and ~~to~~ briefly reviews the program and flight-test results.

1. INTRODUCTION

During the 1970s, increasing demands were made of the general-aviation pilot. Operating procedures were becoming more complicated, regulations were more restrictive, and the demands of the National Airspace System were increasing. During this same period, the general-aviation avionics industry aggressively applied new technology to meet these requirements at affordable prices. However, these developments were along traditional lines with integration occurring only in a few specific areas, such as navigation/communication systems and integrated flight director/autopilot designs. Using this approach of limited integration, the addition of more sophisticated capabilities, such as a performance computer, an intelligent monitoring and warning system, or a ground-proximity warning system, becomes expensive and cumbersome because of the need for separate displays and controls and for signals from aircraft sensors that either do not have an appropriate output or are not easily accessible.

Recognizing this problem, the National Aeronautics and Space Administration initiated a program in 1975 to determine the feasibility of developing an integrated avionics system suitable for general aviation in the mid-1980s and beyond. The objective was to provide information required for the design of reliable integrated avionics that would enhance the utility and safety of general aviation at a cost commensurate with the general-aviation market. The program has emphasized the use of data busing, microprocessors, electronic displays and data entry devices, and improved functional capabilities.

As a final step, in August 1978 a contract was awarded to Honeywell, Inc., teamed with King Radio Corp., for the design and analysis of a projected advanced avionics system (PAAS) concept, and the fabrication and installation of a demonstration advanced avionics system (DAAS), which was capable of demonstrating the most critical elements of PAAS, into a NASA-owned Cessna 402B, twin-engine general-aviation aircraft. The general requirements for DAAS were that it demonstrate the feasibility of designing an integrated system that would provide the pilot with an improved capability and that would be modular, reliable, and easy to maintain. The DAAS acceptance flights were conducted at Olathe, Kansas, in June 1981, and an operational evaluation by more than 100 evaluation pilots and observers, representing all segments of the general-aviation community, was completed in May 1982.

An overview of the program with a summary of the results that led to the DAAS specification is contained in Denery et al. (1978). A preliminary functional description of DAAS is provided in Denery et al. (1979), and a detailed description of both PAAS and DAAS is provided in Honeywell, Inc., and King Radio Corp. (1982a, 1982b). Preliminary results of the flight test are contained in Hardy et al. (1982), and a complete analysis of the flight-test results will be published later this year. The purpose of this paper is to summarize the basic features of DAAS in its final configuration and to address briefly the reliability, maintainability, and pilot acceptability of the DAAS concept based on flight experience.

2. PILOT/SYSTEM INTERFACE DESIGN GUIDELINES

The DAAS pilot/system interface was designed to provide a high degree of flexibility and capability while minimizing operational complexity. The primary interface between DAAS and the pilot is achieved through an electronic horizontal situation indicator (EHSI), an integrated data control center (IDCC), an assortment of function- and mode-select buttons, and a two-axis slew control (Fig. 1). A more complete description of the instrument panel and associated displays and controls is contained in Sec. 4. Specific design guidelines included (1) commonality of electronic display formats for the various DAAS functions; (2) parallel access to all the system capabilities or functions (parallel access means that the pilot can exercise any of the system functions directly without being required to have first performed other functions in an ordered sequence); (3) minimization of the requirement for the pilot to change the displayed information during a normal flight; and (4) designing DAAS to be a source of pilot information but not a decision maker.

To demonstrate these features, DAAS was designed to include (1) an automated guidance and navigation capability, using VOR/DME navigational facilities; (2) standard flight control with navigation coupling; (3) a flight status function, (4) computer-assisted handbook computations such as weight and balance and performance; (5) a monitoring and warning system for alerting the pilot to aircraft mismanagement and engine anomalies; (6) storage of normal and emergency checklists and operational limitations; (7) a data-link capability using the discrete address beacon system (DABS) or Mode S transponder (the FAA-proposed replacement for the ATCRBS transponder); (8) maintenance assistance; and (9) a simulation mode for pilot training and familiarization. These capabilities are described in greater detail below.

3. FUNCTIONAL CAPABILITIES

Guidance and Navigation: The DAAS provides for (1) standard ILS/localizer and VOR/DME navigation; (2) area and vertical navigation with respect to an arbitrary waypoint; and (3) area and vertical navigation with respect to a predefined flightpath specified by a sequence of linked or connected waypoints. The DAAS allows a combination of up to 10 of any of the above waypoints to be stored in nonvolatile memory. In addition, the frequency, station identifier, magnetic variation, elevation, and latitude and longitude for up to ten navigation stations can be stored. The system is mechanized so these navigation facility data can be used to reduce the data entry required for defining specific waypoints.

The area- and vertical-navigation capability is representative of current-generation systems. The measurements from a single VOR/DME are blended with true airspeed, heading, and barometric altitude to provide an improved signal. In addition, the VOR and DME Morse code identifiers are decoded and correlated with the desired station identifier for positive station identification. The navigation outputs include ground speed, ground track, winds, and aircraft position with respect to the selected flightpath.

Flight Control: The flight-director/autopilot is a digital implementation of the King KFC 200 autopilot modified to make it compatible with the DAAS navigation system. The autopilot modes include yaw-damper, heading-select, altitude-hold, altitude-arm, vertical-navigation, navigation-arm, navigation-coupled; approach-arm, and approach-coupled. If the autopilot is coupled to the area-navigation function, the autopilot provides (upon pilot request) automatic transitioning between waypoint inbound and outbound courses.

Flight Status: A GMT clock and fuel totalizer capability is provided; together with the area-navigation capability described above it is used to provide the pilot with a complete assessment of his status. Included are continuous computations of (1) GMT time, ground speed, winds, power setting, and fuel remaining; (2) the distance and time required to reach each waypoint in a predefined sequence of waypoints; and (3) the estimated time of arrival and fuel remaining at each of these waypoints.

Computer-Assisted Handbook Computations: The DAAS provides a capability for assisting the pilot in rapid computations of (1) weight and balance, (2) takeoff performance, and (3) cruise performance. Inputs to the weight and balance calculations, such as fuel load and passenger weight, are entered manually. The DAAS then computes the center of gravity and gross weight and alerts the pilot if the computed values are out of the allowable range. Inputs to the performance calculation can be performed by manual data entry or automatic entry of sensor data such as manifold pressure (MAP), engine rpm, outside air temperature (OAT), barometric altitude, winds, and aircraft weight (using the fuel totalizer function) that may be available in DAAS at the time of the computation. The DAAS then provides estimates of the fuel burn rate, mileage per unit of fuel burned, percent power, true airspeed, and ground speed.

Monitoring and Warning: A significant contribution of an integrated avionics system is its ability to correlate the measurements from different sources and alert the pilot to abnormal or unsafe conditions. To demonstrate this concept DAAS includes an engine-monitoring function, an aircraft-configuration-monitoring function, and a ground-proximity warning function.

The engine-monitoring function provides continuous monitoring of manifold pressure and engine rpm. The aircraft-configuration-monitoring system continually monitors the position of the doors, landing gear, cowl flaps, wing flaps, auxiliary fuel pumps, and trim as a function of aircraft state. In both cases the pilot is alerted to out-of-tolerance conditions.

The ground-proximity warning function is based on Mode 1, defined in ARINC Specification 594-1; it alerts the pilot to excessive rates of descent with respect to the terrain.

Normal and Emergency Checklists and Operating Limitations: The normal and emergency checklists and operational limitations are stored in DAAS so that the pilot can quickly and easily refer to them.

Data Link: The ATC communication, weather, reporting, ATC test messages, or weather information at destination can be communicated to the pilot via the transponder data link and displayed on an electronic display. Future plans call for exercising this capability at the FAA Technical Center in Atlantic City, N.J., with the test ground system. In order to introduce the demonstration pilots to the capabilities of DABS, certain of its features are simulated in the DAAS.

Maintenance Assistance: The DAAS includes built-in test (BIT) to assist maintenance and fault isolation. The BIT is designed to facilitate demonstration of avionics testing in the context of projected advanced general-aviation maintenance concepts that would exist in PAAS. The DAAS also includes an automatic functional-test/fault-localization at powerup or when commanded by the operator, which identifies failed line-replacement units, and an interactive functional test capability which allows the testing of devices when operator actions or observations are necessary to complete a test. For example, electronic display test patterns are included in DAAS to demonstrate interactive testing.

Simulation Mode: By selecting the simulation mode, the DAAS can be exercised on the ground for pilot training. The pilot controls the simulated aircraft through the autopilot mode-select panel. All DAAS displays, controls, and functions can be demonstrated in the simulation mode.

4. DAAS DISPLAYS AND CONTROLS

The DAAS instrument panel is shown in Fig. 1. The DAAS comprises all the instruments on the left side of the panel, the engine instruments, the integrated data control center (IDCC), and the radios located in the center of the panel. The two electronic displays are an electronic horizontal situation indicator (EHSI) and the IDCC. The EHSI provides a function similar to that of an electromechanical HSI but also serves as an electronic map. The IDCC display is used for alphanumeric messages and is the primary means by which the pilot communicates with DAAS. The EHSI and IDCC are discussed in greater detail later in this section. The other instruments are already used in general aviation; based on earlier configuration studies (Denery et al., 1978), the replacement of these instruments with electronic displays would be costly in the demonstration program and would not substantially affect the program objectives. Because DAAS is a research system, the right side of the panel is provided with a set of independent conventional instruments for use by a safety pilot.

EHSI: The EHSI used in DAAS is a 4.5- by 4.5-in. monochromatic CRT raster scan display. It has two formats. One, which is activated when the VOR or ILS navigation mode is selected, provides angular deviation from the desired course in much the same manner as contemporary horizontal situation displays. The other, which is activated when an area-navigation mode is selected, provides a moving-map presentation. The scaling choices for the moving-map presentation include terminal area, 2 n. mi./in.; en route, 8 n. mi./in.; and a 40 n. mi./in. scale to assist the pilot in overall flight planning.

The EHSI, with a moving-map presentation and EHSI controls, is illustrated in Fig. 2. Most of the symbols are self-explanatory. The scale across the top of the display with the "270" digital readout gives aircraft heading. The selected heading is indicated by the heading-select bug on the heading scale and the digital and graphical presentation in the upper left portion of the display. Radio altitude is displayed in the upper right-hand corner when the aircraft is lower than 2,500 ft above the ground. Data pertinent to the active waypoint are shown along the left side of the display. These data include the minimum descent altitude or decision height if the waypoint is an approach waypoint, the active waypoint number; the course, distance, and time to or time from the active waypoint; the waypoint altitude (which is used for both altitude select and vertical navigation); and the VOR/DME receiver being used for navigation. The numeral "1" below the indicated course (CRS 295) indicates that the aircraft is on the inbound course; an outbound course would be indicated by the numeral "2." The WP AVAIL display on the lower right side alerts the pilot when the navigation station associated with the next waypoint is received, based on a periodic scan of the frequency by the DAAS radios. The VTA scale along the right side of the display is used to show the vertical angle between the current aircraft position and the next waypoint. When the vertical navigation mode is engaged, the actual deviation from the derived vertical path is shown on the electromechanical attitude director indicator. The wind magnitude and direction are depicted on the lower right portion of the display. The dashed line projecting from the aircraft symbol indicates projected ground track. Also shown are symbols for the waypoints, the courses connecting sequential waypoints, and navigation facilities within the range of the display.

The controls for the EHSI, which are located adjacent to the display, include a two-axis slew control and EHSI function keys. The slew control is used to (1) slew the map presentation laterally or longitudinally so that the pilot can review the predefined flightpath beyond the normal range of the display or (2) control a cursor on the EHSI display for graphically defining waypoint coordinates. The function keys allow the operator to (1) select a heading-up or north-up map presentation (HDG/NOR); (2) designate whether the slew control is used for slewing the map presentation or controlling a cursor for graphic definition of waypoint coordinates (MAP/CRSR); (3) automatically recenter the map if it has been slewed from the normal position (MAP RTN); (4) add or delete the presentation of an active waypoint bearing needle from the display (WP BRG); (5) review the planned flight, using the map-slew feature during preflight when radio signals are not available (REVU); and (6) select the map scaling (2 NM, 8 NM, 40 NM).

IDCC: The IDCC is shown in Fig. 3. The cathode ray tube is identical to that used in the EHSI display. The display format provides 16 lines of 32 characters. The two bottom lines are reserved for scratch pad, warning messages from the monitoring and warning system, and error messages resulting from invalid data entries. The two top lines are reserved for the title of the selected IDCC display presentation. The remaining portion of the display provides two columns, each with four data entry or selection commands; these commands are activated by the pilot, using the bezel keys along the edges of the display.

The IDCC also contains a set of dedicated function keys along the top. These keys are used to call up specific pages on the IDCC display (PAGE SELECT) or to execute specific functions associated with the DAAS navigation capability (NAV), which include activating the selected waypoint on the IDCC display (USE), activating automatic course change between inbound and outbound courses (AUTO CRS SEQ); manual selection between inbound or outbound course (CRS SEL); and automatic generation of an inbound course from the aircraft present position to the active waypoint (LAT DIR TO).

The keys at the bottom left of the IDCC are used for data entry. A telephone-type keyboard format with three letters on each key is used for alphanumeric entries. The alpha ambiguity, which results from having three letters on each key, is resolved by touching one of the three buttons along the bottom of the keyboard (Fig. 3), thus designating the left, middle, or right letter in a group. A toggle is located to the right of the keyboard for rapid change in the displayed information from one page to another, if a sequence of pages is involved in a particular function.

Figure 4 shows an example of an IDCC display format. This display is presented for the waypoint which is currently being used for navigation when the WP DATA key at the top of the IDCC is pressed. This is referred to as the active waypoint. Waypoint 1 is presented as the active waypoint when the system is first turned on. The label at the top of the display, "WP DATA P 1 of 10," identifies the page. The subtitles adjacent to the asterisks identify the function of the eight bezel keys. Two types of bezel key function entries are illustrated on this page: alphanumeric data entry (first column and first two entries in the second column) and mode select. To enter alphanumeric data, the pilot predesignates the parameter to be changed by touching the key alongside the appropriate subtitle, keying in the desired data, reviewing them in the scratch-pad portion of the IDCC display, and, upon approval, touching the enter key (ENTR) on the IDCC. Upon touching the bezel key alongside the appropriate title, an arrow appears to the left of the quantity to be changed. When two data entries are associated with a single key, such as the frequency (FREQ) and station elevation (ELEV), the arrow can be advanced from FREQ to ELEV by touching the bezel key a second time or by touching ENTR. As mentioned above, on touching ENTR, the quantity in the scratch pad will be entered into the location designated by the arrow. If the scratch pad is clear, the arrow is advanced without altering the stored value. An example of the mode-select function is provided by the MDA OR DH or NAV MODE subtitles. By using the appropriate bezel key, the pilot has the option of (1) designating the waypoint as being an MDA or DH waypoint or (2) navigating in a VOR/ILS mode (VOR/ILS) as opposed to an area-navigation mode (RNAV). The selected mode is indicated by the > symbol which is toggled between the two choices by sequential pressing of the bezel key.

In order to minimize data entry, DAAS automatically enters data where possible. As an example, assume that a waypoint is referenced to a navigation station whose data have been previously stored by using the NAV AID DATA page. Then, on entering the navigation station reference number (NAVAID NO), the prestored station identification (ID) and frequency and elevation (FREQ/ELEV) are automatically entered on the waypoint data page. In addition, if a sequence of the waypoints is entered and referenced to previously stored navigation station data, the DAAS assumes these waypoints are connected, and the DAAS-computed inbound and outbound courses (CRS1/CRS2) are automatically entered. The pilot can change any of these calculated data by using the manual data entry procedure described in the previous paragraph.

The IDCC cruise performance capability is another good example of how the IDCC is used. The CRUISE PERFORMANCE page (Fig. 5) is accessed by pressing the PERF select key at the top of the IDCC, which brings up a menu page listing the various possible performance computations as subtitles adjacent to the bezel keys. Pressing the appropriate bezel key displays page 1 of the two pages associated with the cruise performance shown in Fig. 5. The first page is used for data entry, and the results of the computation are presented on the second page. The first entry on page 1 is labeled DATA ENTRY; it allows the pilot to designate whether he will enter the data manually (MAN) or automatically, using the available sensors (AUTO). As an example, if the pilot selects AUTO, the altitude is entered based on the barometric altimeter reading; winds and course are taken from the navigator; OAT is taken from the temperature sensor; A/C WT is taken from the DAAS-computed aircraft weight, based on the fuel totalizer function; and power is computed, based on engine rpm and manifold pressure. By toggling DATA ENTRY to MAN, these values are retained and the pilot can manually change any of the entries to meet his particular requirements. The results of the performance computation are presented on page 2 (P2 OF 2), which is accessed by using the IDCC BACK-FWD switch in the lower part of the IDCC.

5. SYSTEM ARCHITECTURE

A schematic for PAAS, on which DAAS was based, is shown in Fig. 6. PAAS is a reconfigurable, multiprocessor system organized around a dual bus. Each processor, referred to as a computer processor unit (CPU), consists of a microprocessor, an interrupt controller, a clock, a bus interface module, a read-only memory (ROM), and random access memory (RAM). The system is designed so that each processor is assigned a specific set of tasks. The functional programs reside in the nonvolatile memory. When power is turned on, the bus controller (CPU-1) supervises the loading of the programs into the individual CPU RAM memories. System reliability is achieved by providing a second bus, with bus controller, I/O, and reconfiguration processing unit (CPU-2), to act as a backup for the primary bus, and a spare processor (CPU-7) to act as a backup for the other processor units that do not have direct interface with external sensors (such as CPU-6 and CPU-10). Upon detecting and isolating a failed processor unit other than the bus controllers or CPU-6 and CPU-10, the active bus controller loads the program assigned to the failed processor into the spare processor. Redundancy for CPU-6 and CPU-10 could be provided by multiplexing the respective sensor elements with the spare processor, as was done for the EHSI, CPU-5, or the EADI CPU-9. However, this redundancy is not provided since these functions are not considered to be flight critical; moreover, these particular sensors have a significantly lower reliability than the associated CPU.

A schematic of DAAS is shown in Fig. 7. The DAAS is identical to PAAS, with the exception that it uses a single bus; the sensors and autopilot mode-select panel are interfaced directly with the autopilot, CPU-3; CPU-2 is used only as the radio adapter unit (RAU). These simplifications were made in order to reduce development costs while retaining the capability to evaluate (1) the pilot system interface; (2) the multiprocessor/bus-oriented architectural concept; and (3) certain features of the PAAS reconfiguration concept.

The DAAS uses the IEEE 488 bus. This bus was selected because of the availability of low-cost LSI interface chips and the flexibility provided by the protocol. The computer processor units (other than CPU-2) use the intel 8086, 16-bit microprocessor and have 2 K of 16-bit ROM, and 4 K to 16 K of 16-bit RAM. An Intel 8048, 8-bit microprocessor is used in CPU-2. Electrically erasable PROM (EEPROM) is used for the nonvolatile memory.

6. PROGRAM AND FLIGHT-TEST RESULTS

6.1 Pilot Evaluation

A primary purpose of the DAAS program was to conduct an operational evaluation of the DAAS concept. The major question being addressed was whether the added capability provided by an integrated avionics system could be effectively used by the pilot. Sixty-four flight demonstrations, in which more than 100 evaluation pilots and observers participated, were conducted to answer this basic question. At the conclusion of each flight the subjects were debriefed and asked to complete a questionnaire. Preliminary results from these tests are contained in Hardy et al. (1982). (A detailed analysis is in preparation.) In summary, a significant majority of the pilots who participated clearly felt that DAAS was representative of the way avionics were evolving and that the added capability could be effectively used to improve the safety and utility of the aircraft. The major concerns that were expressed regarded the training that would be required to utilize the full capability of such systems and the ability to apply this training to the operation of other but similar systems.

6.2 Architecture Evaluation

Modularity: The PAAS concept is highly modular because of the bus architecture and multiprocessor concept with its shared displays, controls, and sensors. The modularity was tested in DAAS by adding the DABS function. Although the DABS capability was added several months after the final design was completed and fabrication started, it was easily implemented by adding CPU-6 to the system bus, adding a software module to the IDCC for display and control of the DABS sensor, and adding the address of the DABS function to the bus controller, CPU-1.

Reliability: The PAAS is a fail-operational design. Reliability of the PAAS autopilot and navigation functions was computed to be 9,260 hr between loss of function based on a 1-hr mission. A similar analysis on contemporary flight control and navigation systems showed an expected 201 hr between loss of function.

Since DAAS is a one-of-a-kind system, the reliability experience obtained during the tests cannot be extrapolated to PAAS. However, it is worth noting that DAAS was tested in the Ames Cessna 402B for a period of over 6 months, during which time more than 200 flight hours and 500 power-on hours were accumulated. During this period there were a few minor problems traceable to the commercial-grade card-edge connectors (corrected by reseating the cards and reloading the program). There were no failures of DAAS hardware that required replacement of a component. Of the 60 flight demonstrations that were scheduled none was cancelled because of a DAAS hardware or software failure. The PAAS-reconfiguration concept was tested by artificially inserting faults in the CPU-5. Reconfiguration was complete within 1 sec of fault insertion. The spare processor (CPU-7) was successfully loaded and the mission was not affected.

Maintainability: The self-test and diagnostic features of PAAS have the potential of isolating failures down to the module level. Because of the fail-operative nature of the system design, a module can be removed for repair, as in contemporary systems, while retaining an operative system. As mentioned above, during the DAAS flights there were no hardware failures that required maintenance; therefore, the maintenance features were not completely tested. However, simulated faults were easily identified, using the available interactive functional test and fault-localization capability.

7. CONCLUDING REMARKS

A fully integrated, multiprocessor, advanced avionics system concept, DAAS, was designed, built, and flight tested in a Cessna 402B.

The pilot/system interface was designed to provide a high degree of flexibility and capability while minimizing the operational complexity. Specific design guidelines included (1) commonality of IDCC display format for the various functions; (2) parallel or direct access to all system capabilities, as opposed to sequential access; (3) minimization of the necessity to change display formats during normal flight; and (4) designing DAAS to be a source of information but not a decision maker. Based on the pilot evaluations, these guidelines appear appropriate for the design of avionics for this class of aircraft and mission.

The PAAS architectural concept proved to be highly reliable, maintainable, and modular. State-of-the-art microprocessor technology is easily capable of handling the various functions required in general aviation. The use of a bus architecture allows growth and sharing of limited sensor and display resources between the many subsystems that may be included in a future system. The use of a spare processor for improving reliability by dynamic reconfiguration was successfully demonstrated.

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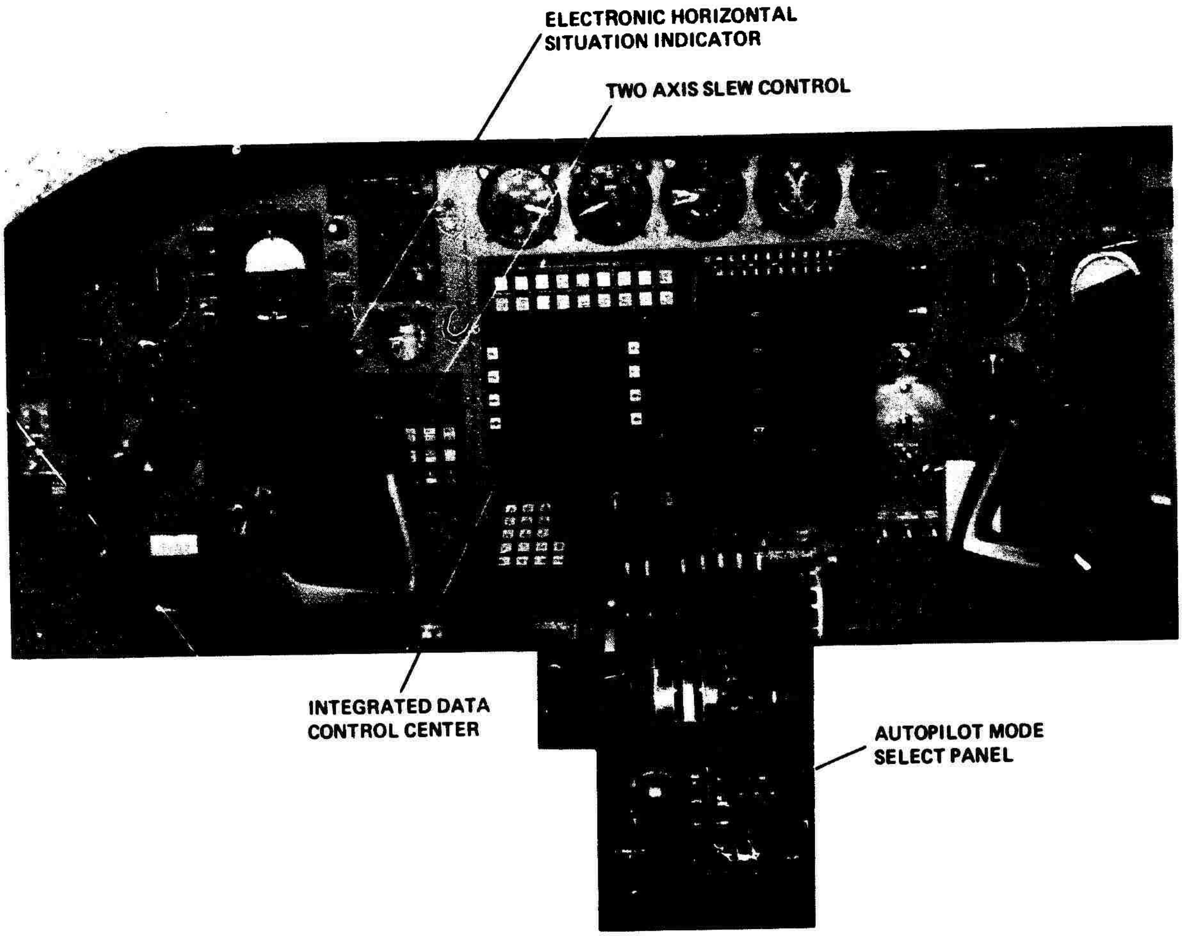


Figure 1. DAAS instrument panel.

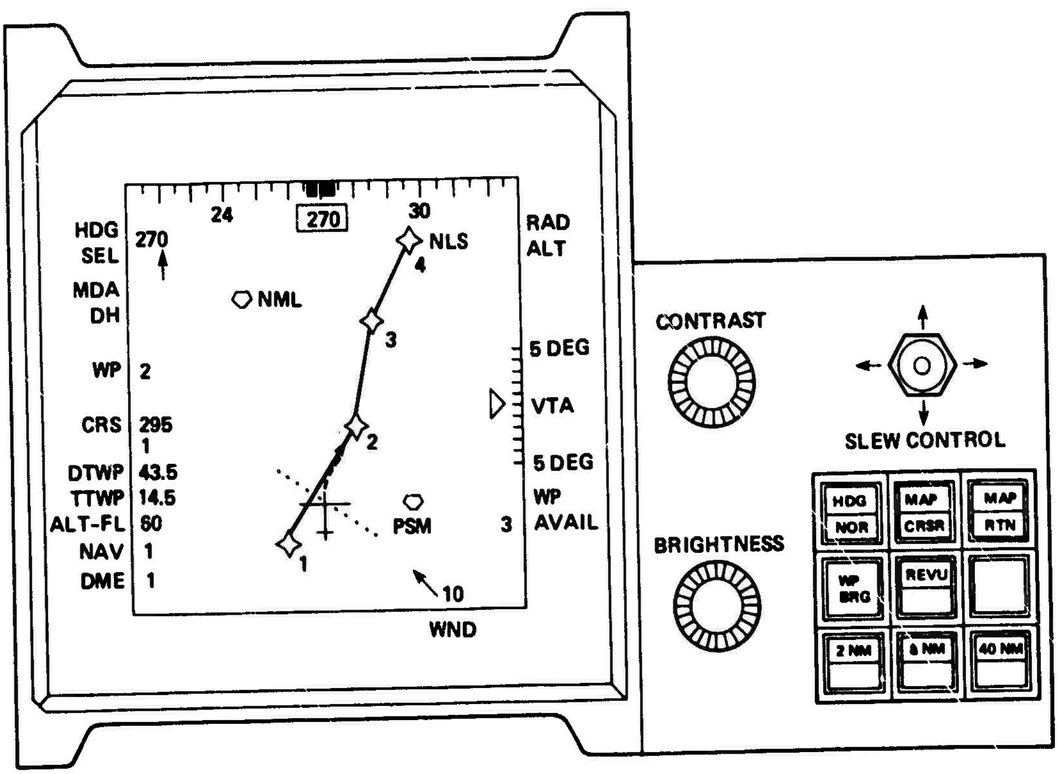


Figure 2. Electronic horizontal situation indicator.

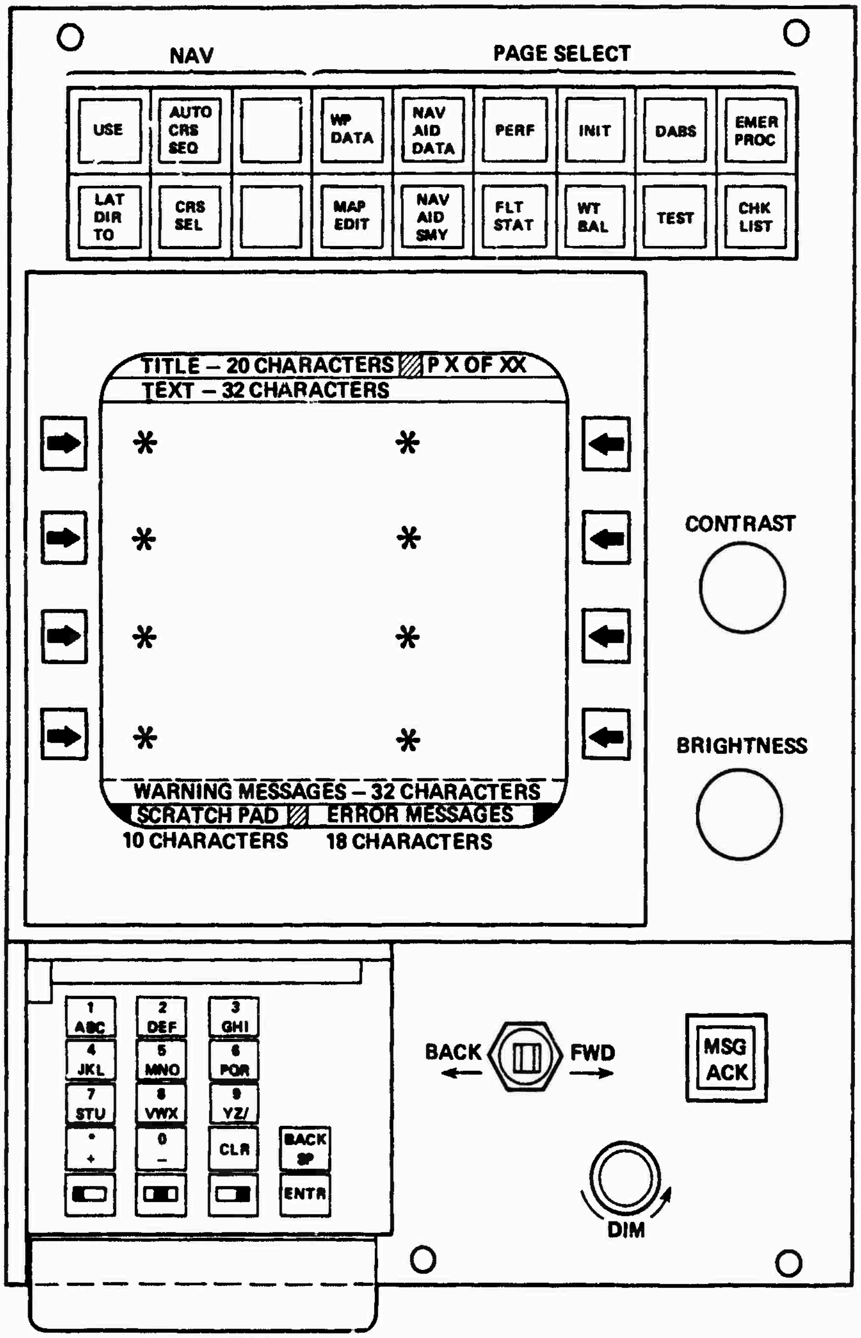
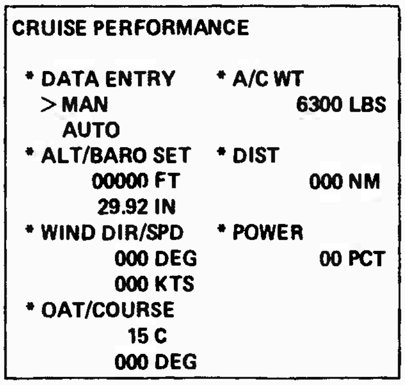


Figure 3. Integrated data control center.

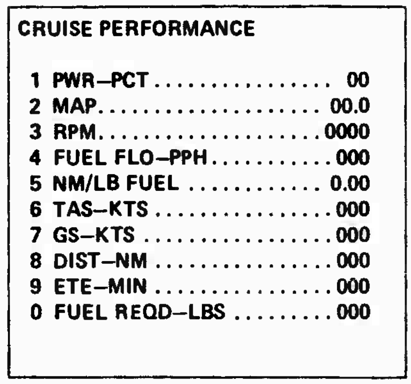
WP DATA P 1 OF 10

* WP NO
  4
* NAVAID NO/ID
  7
  SNS
* FREQ/ELEV
  117.30
  0080 FT
* RAD/DIST
  134.5 DEG
  014.0 NM
* CRS 1/CRS 2
  SEL 238 DEG
  314 DEG
* ALT/OFFSET
  06500 FT
  00.0 NM
* MDA OR DH
  >NO
  YES
* NAV MODE
  >RNAV
  VOR/ILS

Figure 4. Waypoint data page.



(a) P1 OF 2.



(b) P2 OF 2.

Figure 5. Cruise performance.

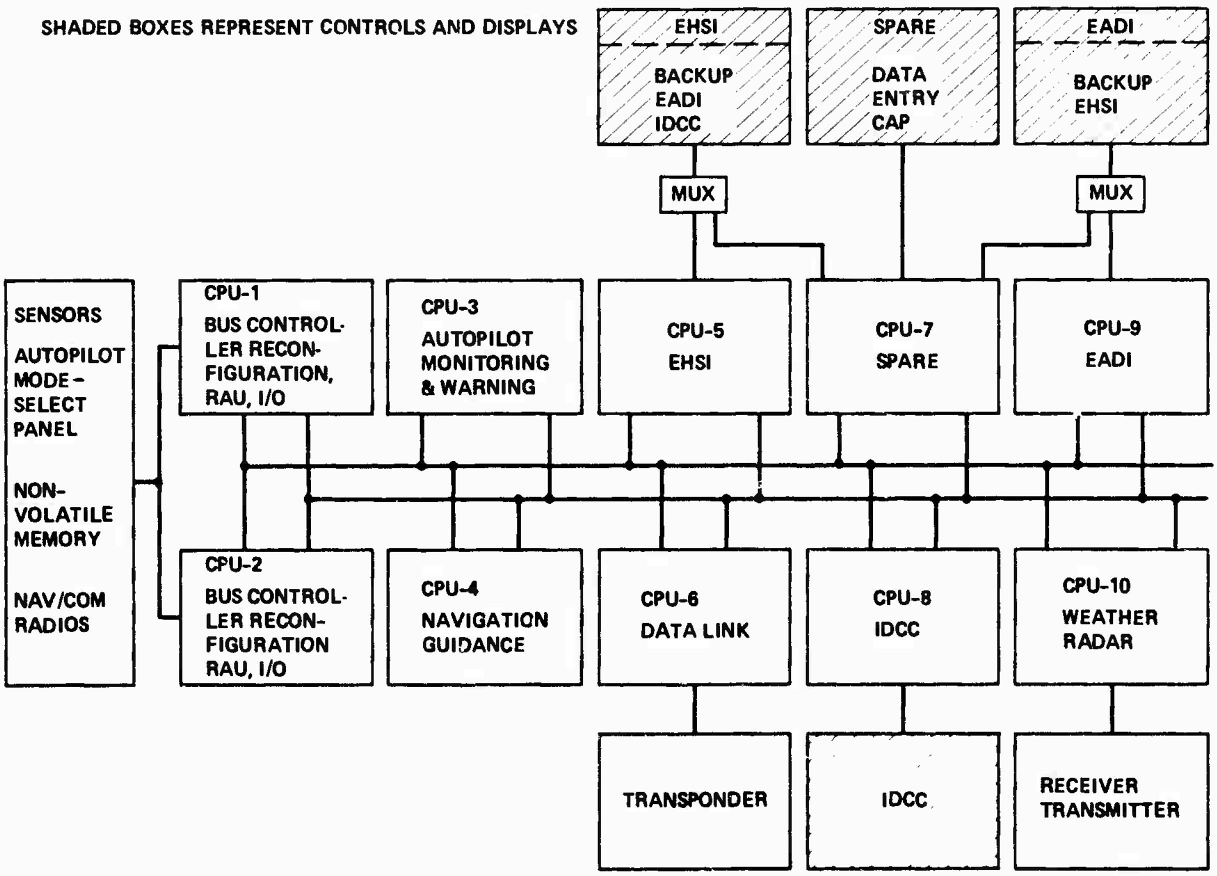


Figure 6. PAAS architecture.

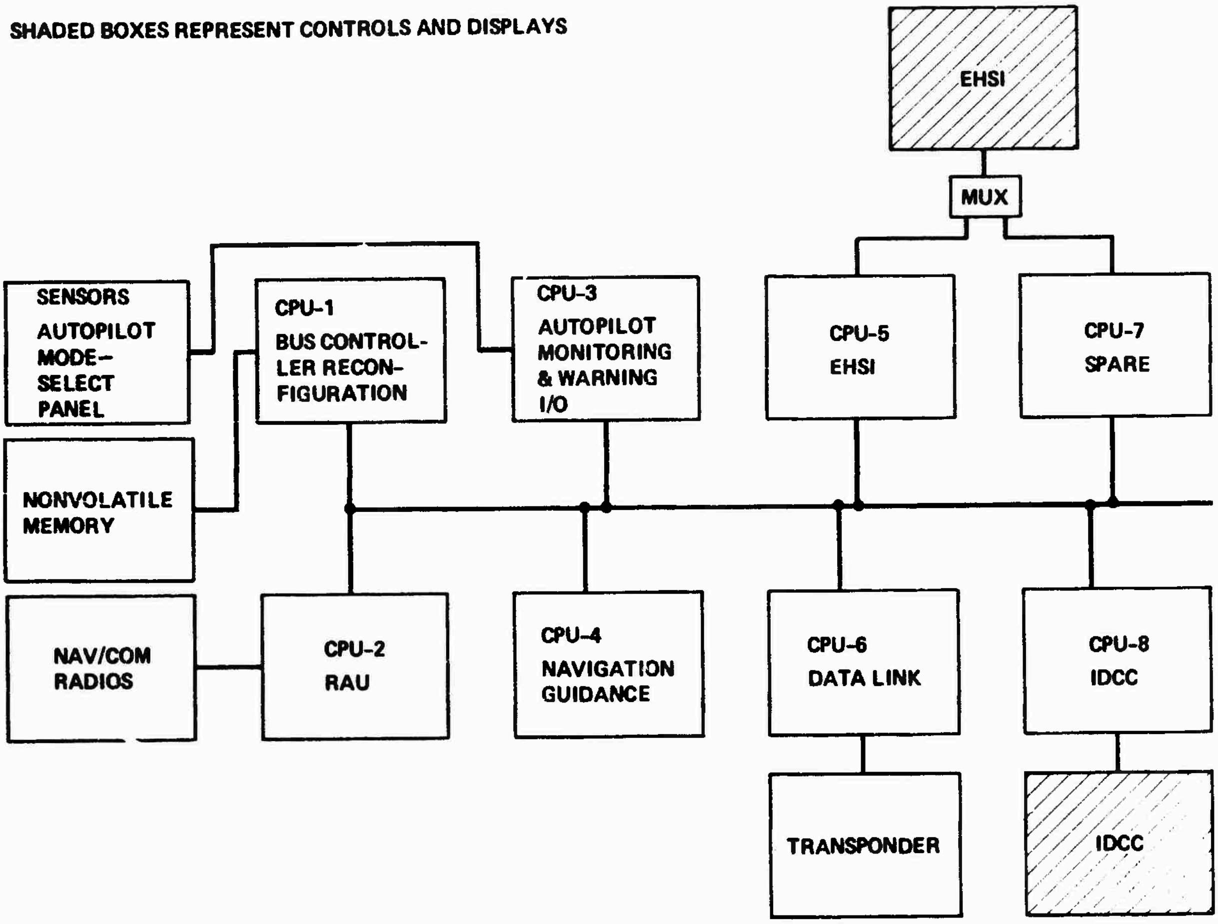


Figure 7. DAAS architecture.

DISCUSSION

R.Q.Laws, UK

In the presented architecture, re-configuration using the spare CPU is apparently achieved by downloading program into the spare CPU via the databus. Is this indeed true?

Author's Reply

Yes.

R.Davies, Ca

(1) With respect to the DAAS questions asked of the pilot community, none required specific answers regarding what cost data would be acceptable over a current standard general aviation suite. I suspect that those owner-pilots of GA aircraft that pay for their own avionics would have a lower dollar figure than those for whom an aircraft is provided and equipped by someone else.

(2) What type of data bus was used and does NASA have any recommendations as to what GA should use in the future? Should there be a general aviation standard data bus or would NASA recommend GA involvement in ARINC/AEEC development of standards such as the airlines ARINC 700 series of "black boxes" with ARINC 600 connectors (and F^3) on an ARINC 429 bus?

Author's Reply

(1) The question is very pertinent but was not asked of the participating pilots.

(2) The DAAS system used the IEEE 488 bus with the Intel 8086 microprocessor as the basic computing element. The IEEE 488 bus was selected because of the availability concept. The DAAS project did not directly address the issue of a data bus standards, however, the general feeling expressed by the FAA, NASA and members of the General Aviation community involved with the project was that the premature application of standards to this market could result in increased costs. It was felt that standards should evolve naturally as a result of market forces and should not be forced on to the manufacturers.

M.Burford, UK

You have successfully demonstrated the use of the spare CPU to give a fault tolerant system. When the system is dynamically reconfigured, may I ask how many words of memory are typically being switched over the bus during this initial phase.

Author's Reply

The number of words transferred over the bus will depend on which processor has failed. For these tests the number of 16 bit words ranged between 8 k and 16 k.

K.F.Boecking, Ge

(1) The PAAS architecture shows a redundant bus system. Do you transmit all messages on both buses simultaneously or do you use the second bus as a standby system?

(2) How do you present an emergency situation to the pilot?

Author's Reply

(1) The PAAS concept is based on transmitting all messages on both buses to provide dual redundant inputs to detect faults with high confidence. The PAAS data bus can be switched manually from dual operation to individual use of either bus.

(2) Warning and caution conditions are brought to the pilot's attention by a red warning light and an amber caution located near the ADI. These direct the pilot's attention to a dedicated portion of the integrated data control center where a caution or warning message is displayed. The pilot pushes a message acknowledge button to extinguish the lights. Multiple warning and caution messages are stored in circular queues with the warning message queue having display priority. Pushing the message acknowledge button rotates the message queues. Messages stay in their respective queue until the conditions causing them are removed, at which point the messages are automatically deleted from the queue.

SUMMARY OF SESSION IV
SYSTEM INTEGRATION AND SYSTEM TEST

by

W.H.Vogl
Session Chairman

Although one would derive from the topic that this session was mainly hardware oriented, very soon it became apparent that not the description of test performance and results was placed in the foreground, but rather that modern methodologies for integrating very complex hardware and software systems have been worked out. Starting of course with some general experience gained during the development of existing and forthcoming Weapon Systems nearly all papers concentrated finally on what was considered the demands for future engineering work: to develop, provide and apply computer-aided integration, simulation and test methods and facilities with all the hardware in the loop. Making use of the advantages of such applications it is thought that development costs for highly complex systems can be kept to an acceptable level, and that safety – and with this, confidence in these systems, can be considerably increased. In this latter view a considerable part of the discussion was also devoted to the man-machine interface investigations.

The session started with paper No.35, titled "Méthodes de Développement du Système de Navigation et d'Armement du Mirage 2000" prepared by Mr Boncorps from Avions Marcel Dassault-Breguet Aviation, and presented by Mr Connan. Being in the Mirage 2000 development and integration business from its beginning, the author reviewed the methods applied to achieve the design aims. In particular, the paper addressed two main elements which helped to overcome the inherent engineering problems for integrating such a complex system: first, close organisational relationship between the designers and the users has to be established from the beginning of the project, to avoid misdirection of any design effort and to meet the commonly defined requirements. Of the same level of importance, however, is the use of highly developed simulation and support devices for dynamic integration on the ground and in the air.

Paper No.36 "Crew Station Evaluation in a Dynamic Flight Simulation Facility" by Mr J.Eyth, Jr of the Naval Air Development Center, explained the unique capabilities and design of the Dynamic Flight Simulation and Crew Station Evaluation Facility built at Warminster, as they pertain to avionics system development and validation. The paper amplified the information tabled earlier during this symposium, to the extent to really assess the system design with the man in the loop in a flight envelope which by far exceeds that of in-flight simulation or flight tests. The simulator enables hazardous flight regimes, such as spins and departures, to be investigated in a repeatable, statistically accurate fashion, with regard to advanced aerodynamic profiles, cockpit displays and controls, crew systems and weapon systems.

In paper No.37, on "Concepts for Avionics and Weapon Systems Integration", Dr F.Kaestner from Messerschmitt-Boelkow-Blohm reviewed the methods and facilities applied to the avionics and weapon integration of the PANAVIA Tornado aircraft. From this proven concept he derived detailed ideas how to respond to the challenges which will arise from advanced, even more complex airborne systems. The overall aim is to develop and install facilities which will allow system hardware and software testing and validation under environmental conditions which are as close as possible to the actual mission environment thus avoiding a high number of time-consuming, expensive flight tests during the development phase. For the actual development flying it remains to demonstrate that the system works to its specification.

Paper No.38 "Hardware-in-the-Loop Simulation Techniques used in the Development of the Sea Harrier Avionic System", co-authored by Messrs M.Mansell, W.J.Quinn and C.J.Smith, of British Aerospace, Brough Division, was presented by Mr Mansell. The paper described the techniques which were adopted to ensure that the hardware and associated software were tested, validated and integrated into the aircraft in an efficient and effective manner. Although the development methods using the simulation with airborne hardware in the loop are well established techniques, each new weapon system produces a different set of problems which require specially tailored measures to cope with. The Dynamic Development Rig is capable of driving the avionic navigation/attack hardware in-the-loop during aircraft attack profiles. The basic sensors were replaced by injection of computerized sensor signals into the system. The dynamic development facility has proved useful for both early evaluation of weapon system problem areas and new system development and has significantly reduced the total flying hours required on such a development programme.

Paper No.39 dealing with "Simulation Requirements to Support the Development of a Fault Tolerant Avionic System" was given by Mr J.Shaw of Northrop Corporation and described the Northrop Avionics simulation package (Executive Support System) which has been designed to support the development of fault tolerant avionic systems and is currently used for the F-5G, F-18L and F-20 avionics models. It provides a mechanism for developing and testing several avionic core configurations as well as avionic simulation and application modules. Through an inter-active interface the user is very flexible in configuring the core avionics system as desired. He is able to define whether centralised or distributed philosophies are to be applied in the system executive. The Support System can be easily tailored to various applications, configurations and anticipated mission scenarios. The ongoing enhancement is aimed at providing one program to stimulate multiple airframes or multiple processing elements in multiple user specifiable configurations

Paper No.40 "Software Testing for Safety Critical Systems" was prepared and presented by Herr J.Stocker of Messerschmitt-Boelkow-Blohm, Military Aircraft Division. From the title of this paper and when addressing the PANAVIA "Tornado" it was obvious that the author wanted to talk about one of the most important aspects of the development and operation of an aircraft which was optimised for TF flying in extremely low altitudes: to provide the high level of confidence into the system which is necessary for such operation profile. This aim is achieved by thorough through-testing using powerful and capable test facilities and adequate hardware and software test concepts. The paper outlined the methods applied for testing the software of the Tornado Autopilot and Flight Director System. The overview of existing test facilities was followed by a detailed presentation of a new automated test tool: the AFDS Cross Software Testing System. Besides the technical advantages of this system like data recording, reproduceability, no timely limitation, and permanent actual-nominal data comparison in real time, the cost saving aspect also for future software modifications and development has been emphasized.

Paper 41 was prepared by Dr N.J.B.Young of Dowty Electronics Ltd. The subject was "Automating the Testing of Software" and provided a summary of challenging concepts for practically useful, cost efficient and automated validation techniques for high integrity software. The paper classified some available techniques against a concept of automatability. Very soon it became obvious that the author's main interest was directed toward the improvement of methods for usefulness rather than for academic purposes. In this understanding the results of detailed studies and applications of "automated symbolic executions" were presented and since the method as such is not a new idea, were compared with other published studies. The pragmatic approach of Dowty, characterized by the question for a "widely applicable device" vs the "perfect device" provides particular advantages of this method, and will be further completed for Defence application.

Paper No.42, the last culmination in this long row of excellent, very professional publications as presented during this symposium, was prepared by Mr R.A.C.Smith of British Aerospace, Aircraft Group (Warton) and reported of "A Dynamic Approach to Military Avionics Systems Testing". Resulting from the experience gained on other aircraft projects, the company has consequently continued in developing advanced test concepts to comply with the requirements of modern, complex avionic systems. Although the pre-flight ground test philosophy remains based on an integrated Avionics System development rig, the techniques presently employed are marked by two main factors, namely the coverage of the interaction between avionics and other airborne systems by extended rig facilities, and the increased use of computing for the data acquisition and simulation tasks, to the extent that a dynamic system testing in a simulated flight is feasible. The dynamic testing technique used for the Tornado Air Defense Version was described in this paper for an example of actual application to prove the aim of reduction of flying hours and increase of effective use of flight testing time available.

METHODES DE DEVELOPPEMENT DU SYSTEME DE NAVIGATION ET D'ARMEMENT DU MIRAGE 2000

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RESUME

La définition, la mise au point et la mise en série d'un système d'armes aussi complexe et intégré que celui du MIRAGE 2000 pose de nombreux problèmes. La présente communication présente les méthodes et moyens utilisés pour le développement du système du MIRAGE 2000.

Les méthodes sont basées sur une étroite collaboration entre les Services Officiels Français, les Industriels et les utilisateurs, l'Armée de l'Air Française. Cette collaboration est concrétisée par la mise sur pied d'une Coordination Industrielle chargée par les Services Techniques d'établir des dossiers de travail qui sont ensuite examinés à différents niveaux par toutes les parties intéressées.

Les moyens sont essentiellement basés sur l'utilisation d'un simulateur, d'avions de servitude, d'un banc d'intégration dynamique, d'un avion d'intégration et d'avions prototypes.

L'association de nouvelles méthodes de travail et de moyens de développement sophistiqués permet d'aboutir à une définition de système complexe conforme aux demandes des utilisateurs dans les meilleurs délais et à moindre coût.

1 - INTRODUCTION

Le MIRAGE 2000 est équipé d'un Système de Navigation et d'Armement (SNA) entièrement numérique. La plupart des équipements disposent de calculateurs numériques et dialoguent entre eux par l'intermédiaire d'une liaison numérique multiplexée appelée Digibus. L'utilisation de cette technologie offre par ailleurs plus de souplesse et plus de capabilités pour la définition des fonctions opérationnelles.

Les problèmes d'architecture dans la conception d'un tel système sont complexes ; les fonctions opérationnelles de tous les équipements sont hautement intégrées. Ces raisons ont conduit les Services Officiels Français et les Industriels à définir des méthodes élaborées pour assurer la définition et le développement du Système de Navigation et d'Armement (SNA) du MIRAGE 2000.

Le but de cette communication est de décrire ces méthodes et les moyens utilisés dans les différents stades de la conception, de l'établissement des spécifications, de la réalisation, de la mise au point et du passage en série. Nous n'aborderons que les aspects liés à l'intégration du SNA et non pas ceux liés à un équipement donné ou au logiciel d'un équipement donné qui peuvent faire l'objet de communications différentes spécifiques.

2 - METHODES DE TRAVAIL

Les systèmes d'armes des avions modernes se caractérisent par la présence à la fois de fonctions propres à chaque matériel et de fonctions système qui intéressent tous les équipements et donc tous les industriels. L'idée de base consiste donc à faire travailler ces industriels en étroite association pour la conception et le développement du SNA.

Les méthodes de travail retenues pour assurer le développement du Système de Navigation et d'Armement du MIRAGE 2000 reposent sur la création d'une Coordination Industrielle. Il s'agit d'une équipe regroupant des représentants de l'avionneur - en l'occurence les AMD-BA - et des industriels fabricants d'équipements.

Cette équipe est chargée de la réalisation d'un certain nombre de tâches sous contrat des Services Techniques de l'Etat et des réunions régulières avec ces Services Techniques et avec l'Etat Major de l'Armée de l'Air (E.M.A.A.) sont prévues à tous les niveaux hiérarchiques et aux divers stades d'avancement des tâches demandées.

L'équipe de coordination a essentiellement pour but de définir tous les éléments du SNA et d'aider à la définition des moyens de développement nécessaires pour la mise au point du SNA sous l'aspect de l'intégration du système : en effet pour assurer toutes les fonctions demandées aux systèmes d'armes modernes, les techniques numériques sont les seules à pouvoir répondre au besoin, et cela se traduit par des intéractions permanentes entre les différents composants du système. La création de l'équipe de coordination a donc pour but de mettre de façon permanente en présence les différents industriels concernés pour obtenir une définition cohérente de l'ensemble du SNA.

Le marché de coordination est notifié par les Services Techniques à l'avionneur, c'est-à-dire les AMD-BA qui en détiennent la responsabilité et qui sont chargés de l'animer en suscitant tous les travaux nécessaires. Lorsqu'il y a divergence entre les divers membres de la coordination, c'est l'avionneur qui est l'arbitre et c'est son avis qui prévaut. Cependant dans ce dernier cas, il y a présentation aux Services Techniques de l'Etat des différentes positions et ce sont eux qui prennent la décision finale.

2.1 Tâches de la coordination

La coordination a pour tâche de suivre le développement du SNA depuis les premières définitions initiales jusqu'à la mise en série de l'avion et d'assurer la gestion du programme de développement.

2.1.1 Définition initiale du SNA

A partir d'une fiche programme établie par l'Etat Major de l'Armée de l'Air, le rôle de la coordination est d'exploiter les études effectuées auparavant dans les domaines intéressés et d'analyser les possibilités techniques et technologiques du moment pour proposer les principaux objectifs à prendre en compte pour la définition du SNA. Ces objectifs sont discutés avec les Services Officiels afin de déterminer les hypothèses de base de la suite des travaux.

2.1.2 Définition générale du SNA

Les tâches de la coordination consistent alors à rédiger une série de documents qui doivent permettre de définir les principales fonctions du SNA, les grandes options sur l'utilisation de l'avion et de son système d'armes ainsi que les documents généraux de référence :

- Liste des fonctions opérationnelles.
  Une première définition des principaux modes de fonctionnement du SNA est décrite dans ce document.

- Architecture matérielle et logicielle.
  Ce document présente la liste des principaux équipements du SNA et les fonctions qu'ils remplissent, ainsi que l'architecture logicielle, c'est-à-dire les principes de répartition des tâches de calcul entre les équipements et la définition du dialogue entre ces équipements.

- Analyse logique du SNA.
  Ce document présente les principaux modes de fonctionnement des équipements et du SNA ainsi que toutes les commandes disponibles. A partir de ces éléments il est défini une logique système, c'est-à-dire les règles de priorité entre modes de fonctionnement des équipements et modes de fonctionnement du SNA et les règles d'affection des commandes selon les modes de fonctionnement des équipements et/ou du SNA.

- Philosophie des visualisations.
  Ce document établit les règles générales de définition des visualisations à la disposition de l'équipage, en particulier les types d'informations présentées sur les visualisations cathodiques et les principes de répartition entre tête haute et tête basse.

- Philosophie des pannes.
  Ce document présente les règles générales qui dictent la présentation des informations de panne à l'équipage.

- Spécifications générales du digibus.
  Le système de navigation et d'armement est articulé autour d'une liaison numérique multiplexée reliant les principaux équipements appelée digibus. Ce document précise toutes règles générales d'utilisation et de couplage au digibus auxquelles doivent se conformer les équipements qui y sont reliés.

- Spécifications générales de maintenabilité au premier échelon.
  Ce document précise les règles auxquelles doivent se conformer tous les équipements afin de pouvoir disposer d'un système cohérent au point de vue maintenabilité et en particulier dans le cas du MIRAGE 2000 d'avoir une maintenance au 1er échelon presque totalement intégrée dans l'avion lui-même.

- Spécifications générales de maintenabilité au deuxième échelon.
  Ce document précise les règles générales de la maintenance en atelier et en particulier pour le MIRAGE 2000 le couplage à un banc automatique de test unique pour tous les équipements du SNA.

- Spécifications générales des équipements.
  Ce document précise les règles générales auxquelles les équipements doivent se conformer : application des normes, conception et fabrication, conditions d'environnement, essais des équipements prototypes ...

2.1.3 Définition détaillée du SNA

A partir des règles générales retenues lors de la phase précédente du développement, la coordination a pour tâche de réaliser la définition détaillée du SNA, c'est-à-dire aboutir à la définition précise des équipements - matériel et logiciel - ainsi que de leurs interfaces analogiques et numériques.

Les différents documents rédigés à ce niveau sont les suivants :

- Spécifications globales des fonctions.
  Pour chaque mode de fonctionnement du SNA (navigation, conduites de tir d'armes air-sol et air-air ...), un document définit le système de façon globale, c'est-à-dire tel qu'il est vu par l'équipage : ce sont en particulier les différentes phases possibles à l'intérieur d'une fonction donnée, les commandes utilisées et les visualisations associées.

- Spécifications détaillées des fonctions opérationnelles (SDFO).
  Pour chaque mode de fonctionnement du SNA, et pour chaque calculateur concerné, ce document décrit les fonctions à réaliser sous forme de logiciel dans un langage compréhensible par une personne ne connaissant en rien l'informatique.

- Clauses techniques d'intégration (CTI) des équipements.
  Pour tous les équipements du SNA, ce document présente la définition du matériel, ses fonctions, ses interfaces avec le reste du SNA, ses conditions d'installation dans l'avion, sa mise en oeuvre, sa fiabilité et ses performances.

- Fiches d'interfaces analogiques.
  Ce document regroupe la définition détaillée de toutes les liaisons analogiques du SNA une par une : nature de la liaison, équipements émetteur et récepteur, outils d'entrée et de sortie, type de câblage ...

- Fiches d'interfaces numériques.
  Ce document est certainement le plus important et le plus représentatif de tous les travaux d'intégration du SNA. Il définit en effet en détail toutes les informations échangées sous forme numérique entre les équipements, c'est-à-dire la grande majorité d'entre elles : nom de l'information, équipement émetteur, équipement(s) récepteur(s), fréquence de transmission, nombre de bits représentatif, définition du LSB, résolution ...

- Synoptiques de câblage.
  Ces synoptiques représentent l'ensemble des liaisons entre équipements du SNA en précisant notamment les types de prise et les brochages de chaque prise. Ils permettent d'établir les schémas et les liasses de réalisation des câblages de l'avion.

Répartition des fonctions matérielles et logicielles.

Les fonctions réalisées par les équipements peuvent être réparties en deux catégories :

- Les fonctions autonomes.
  Ce sont les fonctions réalisées sous forme matérielle et/ou logicielle et qui ne dépendent pas d'informations élaborées par d'autres équipements. Dans ce cas seules les clauses techniques d'intégration (CTI) et les fiches interfaces définissent de telles fonctions réalisées par un équipement donné. C'est par exemple le cas de toutes les fonctions capteur réalisées dans une centrale aérodynamique ou dans une centrale à inertie.

- Les fonctions intégrées.
  Ce sont les fonctions qui dépendent d'informations élaborées par d'autres équipements. Ce sont par définition les fonctions opérationnelles du SNA, celles qui font l'objet de plus de problèmes de mise au point et de validation et qui doivent bénéficier de la souplesse offerte par le logiciel. Elles se trouvent donc être toujours réalisées sous forme logicielle et sont définies par les spécifications détaillées des fonctions opérationnelles de l'équipement donné et par les fiches interfaces.

C'est au niveau de détail des CTI, des SDFO et des fiches interfaces que s'arrêtent les tâches de la coordination : c'est en effet la concrétisation au niveau de chaque équipement des analyses générales d'intégration et de la répartition entre les équipements des différentes fonctions à réaliser pour assurer le bon fonctionnement du SNA. Les travaux consécutifs - le choix des composants, la définition intérieure de l'équipement, la réalisation du logiciel - ne sont plus du ressort de la coordination mais de l'équipementier lui-même.

2.1.4 Mise au point du SNA

La coordination assure le suivi de la mise au point du SNA sur les différents moyens de développement prévus. Cette mise au point se traduit par de nombreuses modifications aussi bien matérielles que logicielles par rapport à la définition de référence du système décrite dans les documents CTI, SDFO et fiches interfaces. De façon à être en mesure d'identifier à tout instant la définition précise et complète du SNA, il est nécessaire de mettre sur pied des procédures très rigoureuses auxquelles tous les industriels concernés doivent se conformer. Toute modification, aussi minime soit-elle, par rapport aux documents de référence doit donc faire l'objet d'une fiche d'évolution. Les fiches d'évolution sont rédigées soit par des membres de l'équipe de coordination soit par des membres des équipes de mise au point ; mais elles doivent avoir l'accord de la coordination avant toute diffusion pour étude ou application de façon à s'assurer que les modifications demandées ne remettent pas en cause les principes retenus au début du programme de développement et la cohérence d'ensemble du SNA et que par ailleurs elles n'ont pas de conséquences inattendues sur d'autres équipements ou d'autres fonctions.

Pendant la phase de développement et par le jeu de l'application successive des fiches d'évolution, on se retrouve toujours dans la situation où il existe plusieurs versions de logiciel pour un même équipement et/ou des modifications de câblage appliquées sur un moyen de développement et pas encore sur un autre. C'est également une des tâches de la coordination de tenir à jour la définition précise des différents équipements et moyens de développements utilisés pour la mise au point du SNA, de définir les contraintes de simultanéité d'application de certaines fiches d'évolution ainsi que les états de compatibilités entre diverses versions de matériels et/ou logiciel.

2.1.5 Série

Lorsque l'avion est en série, il s'agit d'établir avec précision la définition aussi bien matérielle que logicielle des équipements du SNA : le "standard" SNA est une entité caractérisant à un stade de définition donné le système d'armes de l'avion. La définition du standard est caractérisé par :

- un descriptif exhaustif des capabilités opérationnelles de l'avion,
- une liste des références de tous les équipements,
- une liste des caractéristiques de l'avion capable d'accueillir ces équipements.

Par ailleurs la référence d'un équipement est constituée par juxtaposition du type et de l'état de l'équipement. Le type sert à identifier la fonction opérationnelle de l'équipement et ne prend en compte que les seuls critères d'interchangeabilité au 1er échelon. En d'autres termes le type n'évolue que lorsque interviennent des modifications touchant les interchangeabilités mécanique, électrique, opérationnelle ou de maintenance 1er échelon. La notion d'état n'intervient que pour les équipements complexes comportant plusieurs sous ensembles pouvant être changés au 2ème échelon. Les différentes combinaisons de ces sous ensembles forment des états et sont répertoriées dans une grille de compatibilité.

Il appartient à la coordination de définir les différents standards et les grilles de compatibilités types/standards correspondantes en fonction des objectifs calendaires fixés par les utilisateurs.

Compte-tenu des conséquences importantes de l'évolution de la définition du SNA en série sur la maintenance, la documentation, les moyens de formation au sol des personnels de l'Armée de l'Air, la définition d'un nouveau standard n'a lieu qu'à une fréquence au plus égale à l'année et les procédures d'approbation et d'application sont plus complexes et plus longues que pendant la phase de développement où les modifications doivent être appliquées très rapidement.

2.1.6 Gestion du programme

Pendant toute la phase de développement du SNA, la coordination a pour tâche de fond la gestion d'ensemble du programme. Cette gestion consiste à définir en début de programme les moyens de développement et les besoins en équipements correspondants et surtout à assurer le suivi régulier du plan de développement technique. La méthode PERT est utilisée et la coordination a défini l'ensemble des sous réseaux regroupant toutes les phases du développement. La mise à jour du réseau complet a lieu tous les trois mois au cours d'une réunion avec toutes les parties intéressées pour prendre immédiatement toutes les dispositions nécessaires en cas d'annonce de retards.

2.2 Fonctionnement de la coordination

Le fonctionnement de la coordination met en oeuvre plusieurs types d'organisation du travail selon les sujets à traiter. Par ailleurs les tâches à réaliser s'intègrent dans deux schémas différents.

2.2.1 Organisation des travaux

L'équipe de coordination se compose d'un certain nombre de représentants de tous les industriels concernés, travaillant en permanence en liaison étroite entre eux sur les diverses tâches de la coordination. Si l'étude d'un sujet particulier doit faire appel à des spécialistes, on crée un groupe de travail chargé d'analyser et d'effectuer tous les travaux relatifs au sujet donné. Certains groupes de travail peuvent ne comprendre qu'un nombre limité d'industriels en fonction du sujet concerné. C'est ainsi qu'ont été créés les groupes de travail architecture, air-air, maintenance, contre-mesures.

2.2.2 Types de tâches

Deux types de tâchas ont été identifiés. Les tâches courantes sont les tâches de fond de la coordination évaluées de façon forfaitaire et qui doivent mener à la réalisation de tous les documents cités au § 2.1. Les tâches ponctuelles correspondent à des études bien précises dont le besoin apparaît au fur et à mesure de l'avancement des tâches courantes. La coordination fait alors aux Services Techniques une proposition technique et financière d'une étude ponctuella dont le contenu, l'objectif et l'aboutissement sont clairement identifiés.

2.3 Liaisons avec les Services Officiels

Le principe de base de fonctionnement de la coordination consiste à la réalisation par celle-ci des différents documents correspondant aux phases successivas du développement citées ci-dessus. Lorsque la coordination a réalisé un document de définition, celui-ci est transmis aux Servicas Techniques et à l'Armée de l'Air pour examen. Des réunions sont alors organisées entre la coordination et les Services Officiels pour la discussion du document, pour fournir les explications complémentaires demandées et aboutir à la définition qui agrée toutes les parties intéressées. La coordination diffuse alors le document définitif qui devient la référence.

Pour assurer ce processus de travail général, un certain nombre da rencontres particulières viennent ponctuer le travail de la coordination afin d'assurer une liaison étroite et régulière avec les Services Officiels.

2.3.1 Point coordination

Le point coordination est une réunion qui a lieu toutes les trois semaines entre l'équipe de coordination et les Servicas Techniques. Cette réunion a pour but de faire le bilan des réunions passées, de faira un bref résumé de leur contenu ainsi que de définir et d'organiser toutes les réunions à venir. Toutes les réunions sont citées, qu'elles aient lieu seulement entre Industriels, antre Industriels et Services Techniques ou antre Industriels, Services Techniques at l'Armée de l'Air. Au point coordination sont également et rapidement abordés l'avancement das travaux des différents groupes de travail et les points divers susceptibles d'intérasser les participants.

2.3.2 Avancement semestriel

Tous les six mois, une réunion avec les plus hautes autorités du programme MIRAGE 2000 des Services Techniques et de l'E.M.A.A. fait un point de l'avancement général des travaux depuis la réunion précédente : les travaux de la coordination et les essais sur les divers moyens de développement.

2.3.3 Réunions techniques particulières

A chaque fois que la coordination le juge nécessaire pour la bonne suite de ses travaux, elle demande une réunion technique sur un sujet particulier avec les Services Techniques et si nécessaire, selon le sujet, avec l'Armée de l'Air.

Par ailleurs, chaque groupe de travail a des réunions régulières entre industriels et périodiquement les Services Techniques sont invités à l'une de ces réunions pour faire un point précis des travaux en cours.

2.3.4 Réunions d'approbation des fiches d'évolution

Toutes les fiches d'évolution diffusées par la coordination font l'objet de réunions périodiques avec les Services Techniques et l'E.M.A.A. pour décider de leur acceptation et des conditions d'application dans les divers équipements. Les réunions ont lieu à plus grande fréquence lors de la phase de développement (de l'ordre de 2 mois) qu'après la mise en série de l'avion (de l'ordre de 4 mois).

2.3.5 Fournitures contractuelles

Compte-tenu des aléas de définition et des divers paramètres à prendre en compte, la plupart des documents que doit fournir la coordination ne font pas l'objet de dates contractuelles de diffusion. Les seules fournitures contractuelles de la coordination sont les suivantes :

- La mise à jour du planning de développement technique du programme sous forme PERT tous les trois mois.
- Un document faisant le point de l'avancement des travaux de la coordination tous les six mois : il s'agit en fait du compte-rendu de la réunion d'avancement semestriel.
- Un document pour chaque groupe de travail faisant le point de l'avancement des travaux de ce groupe tous les six mois : dans ce document figurent en particulier les compte-rendus de toutes les réunions du groupe.
- Les dossiers d'étude pour chaque étude ponctuelle qu'il a été jugé nécessaire d'effectuer.

2.4 Bilan de la coordination

L'expérience acquise à ce jour a montré que l'organisation de la coordination industrielle répondait bien aux objectifs fixés. Les liaisons étroites que les industriels ont été tenus d'entretenir entre eux pour la définition de l'ensemble du système de navigation et d'armement ont permis d'aboutir à un système efficace et cohérent. Mais il est également apparu que le rôle des AMD-BA en tant que responsable et animateur de la coordination était essentiel. En effet il est souvent arrivé, et ceci est parfaitement normal et naturel, que tel ou tel industriel ait tendance à proposer des solutions qui avaient des avantages pour ses équipements mais qui présentaient par contre des inconvénients pour l'ensemble du SNA. C'est alors que les AMD-BA intervenaient en tant qu'arbitre neutre puisque ne fabricant aucun équipement et ayant pour seul objectif de définir un système cohérent et homogène. C'est ainsi que ce sont plus particulièrement les AMD-BA qui ont rédigé, avec l'accord des autres coopérants bien entendu, tous les documents de spécifications générales du SNA : spécifications générales des équipements, spécifications générales du digibus, spécifications générales de maintenance, philosophie des commandes et des visualisations, philosophie des pannes ...

3 - MOYENS DE DEVELOPPEMENT

Les systèmes de navigation et d'armement modernes se caractérisent essentiellement par leur haut niveau d'intégration dans les différents équipements constituant le SNA et par la banalisation des commandes et visualisations, ceci grâce à l'utilisation de calculateurs numériques et de visualisations cathodiques. La mise au point d'un système d'armes complexe doit donc utiliser des moyens de développement capables de traiter d'une part les problèmes de logiciel et d'autre part les problèmes d'ergonomie. L'analyse a montré que de tels moyens doivent être assez complets pour permettre une investigation aussi exhaustive que possible des logiciels temps réel, et assez souples pour s'adapter très rapidement aux demandes des pilotes évaluateurs. Par ailleurs il est apparu que de nombreuses phases d'essais pouvaient se faire au sol et qu'il n'était pas possible de monter des installations d'essais complexes sur l'avion d'armes lui-même.

Ces diverses considérations nous ont conduit à définir différents moyens de développement permettant la mise au point depuis l'installation laboratoire au sol jusqu'à l'avion prototype lui-même avec un enchaînement logique dans les phases successives de la validation d'un système d'armes.

3.1 Système d'animation visualisation

3.1.1 Définition

Ce système se compose d'un manche, d'une manette de gaz, d'un clavier avec de nombreux interrupteurs pour simuler les commandes et d'un écran cathodique polychrome pour visualiser tête haute et tête basse. Ce simulateur dispose d'un modèle avion, travaille en temps réel, et est mis en oeuvre par les AMD-BA qui assurent en outre toute la programmation nécessaire.

3.1.2 Rôle

Ce système a pour but de permettre une première étude des visualisations correspondant à un mode de fonctionnement du SNA. Il permet de définir les formes de réticules, la nécessité de certaines informations, la répartition entre tête haute et tête basse. C'est à partir de cette première préétude que peuvent être écrites les spécifications globales des fonctions du SNA.

3.2 Simulateur d'étude

3.2.1 Définition

Le simulateur d'étude est une cabine de pilotage montée sur une plate-forme 6 axes. Un système de visualisation permet de représenter le sol, soit un aérodrome et ses environs pour la simulation de l'approche, soit un terrain réel pour la simulation de la navigation basse altitude. La cabine est équipée des équipements de pilotage, des visualisations cathodiques tête haute et tête basse et des principales commandes nécessaires pour la mise en oeuvre du SNA.

Ce simulateur est mis en oeuvre par un Service de l'Etat, le Centre d'Essais en Vol (C.E.V.) mais le logiciel du simulateur est réalisé pour la plus grande partie par les industriels de la coordination garants de la cohérence des logiciels de simulation et de la définition de base du SNA. Les documents de référence pour ce simulateur sont les spécifications globales des fonctions du SNA.

3.2.2 Rôle

Le simulateur d'étude a pour but d'étudier l'aspect ergonomique du SNA, c'est-à-dire les commandes et visualisations associées aux différents modes de fonctionnement du SNA. Les essais se font dans un environnement représentatif avec une simulation en temps réel de tous les éléments mis à la disposition du pilote.

Divers pilotes évaluateurs volent sur ce simulateur, formulent toutes leurs remarques et proposent des modifications par rapport aux définitions "papier" à partir desquelles il est toujours difficile de juger ce que vont représenter en dynamique des visualisations données.

Pour que ce simulateur ait un rôle utile dans le programme de développement, il faut bien sûr que les essais d'évaluation aient lieu assez tôt pour en tirer les conséquences et les appliquer au cours de la réalisation des logiciels des équipements embarqués.

3.3 Banc de génération électrique

3.3.1 Définition

Ce banc se trouve en laboratoire et est représentatif de la véritable génération électrique de l'avion : alternateurs, transfo redresseurs, batterie, câblages. Ce banc est mis en oeuvre par les AMD-BA.

3.3.2 Rôle

Le but de ce banc est de vérifier le fonctionnement correct de la génération électrique en présence d'un puis de plusieurs, enfin de tous les équipements qui y sont connectés. Il y est en particulier étudié toutes les conséquences sur les niveaux de tension alternative et continue de la mise en marche et de la coupure des équipements du SNA. Les bilans de consommation de chaque équipement selon leurs modes de fonctionnement sont également mesurés sur ce banc.

3.4 Avions de servitudes

Plusieurs avions de servitude spécialisés sont mis en oeuvre par le Centre d'Essais en Vol. Ils n'ont pas pour but de contribuer à la mise au point du système d'armes intégré mais à celle des équipements complexes du SNA. En effet les essais d'intégration ne sont censés débuter que lorsque les équipements eux-mêmes sont au point. Les avions de servitude suivants ont ainsi participé au programme MIRAGE 2000 : un avion pour le radar, un avion pour les systèmes de contremesures, un avion pour le couplage du radar à l'autodirecteur du missile air-air.

3.5 Banc d'intégration

3.5.1 Définition

Le banc d'intégration mis en oeuvre en laboratoire par les AMD-BA est la pièce maîtresse de l'intégration du système d'armes. Il a pour but d'assurer le bon fonctionnement de tous les équipements du SNA reliés entre eux comme sur avion et d'obtenir une optimisation des performances globales du système. Pour atteindre cet objectif, le système peut être excité de deux façons complémentaires :

- statique : c'est la simulation
- dynamique : c'est la stimulation, méthode originale mise au point par les AMD-BA et utilisée sur différents programmes depuis 1975.

Le banc d'intégration se compose de différents éléments :

- Des baies comportant :
  . les équipements réels de l'avion reliés par un câblage type avion.
  . la génération électrique de l'avion excitée par une génération électrique de laboratoire.
  . des simulateurs analogiques et digitaux pouvant se substituer à des équipements réels.
  . des simulateurs d'armements.
  . divers moyens de surveillance et appareils de mesure.

- Des moyens extérieurs de mise en oeuvre :
  . des terrasses permettant l'installation de radars et/ou de missiles avec possibilité d'émission radar.
  . des baies de test ou de mise en oeuvre des principaux équipements du SNA : radar, calculateurs, centrale à inertie ...
  . un support harmonisable de centrale à inertie.

3.5.2 Essais statiques

3.5.2.1 Nature des essais statiques

Ces essais consistent à mettre le système complet sous tension et à contrôler le bon fonctionnement de l'ensemble dans un certain nombre de configurations statiques du SNA. Ils permettent ainsi de procéder aux opérations de mise au point suivantes :

. Adaptation et performances des interfaces matériel.
. Sensibilité du système aux coupures et variations de la génération électrique.
. Performances des détecteurs : centrale à inertie, centrale aérodynamique.
. Contrôle des précisions des paramètres de sortie du système sur les organes de visualisations.
. Contrôle des logiques de commande et de pannes.
. Correction des erreurs de logiciel dues à des erreurs de programmation ou à des défauts de principe.

3.5.2.2 Limitations des essais statiques

De part leur nature, ces essais sont limités. Seuls en effet sont traités les problèmes d'interfaces matériels et les problèmes de logique sur un nombre nécessairement restreint d'échantillons. Par ailleurs tous les problèmes liés à la dynamique, tels que filtrage, extrapolation, bruit, précision dynamique ... d'autant plus importants que les fonctions sont réparties dans différents calculateurs numériques reliés par une liaison numérique multiplexée, ne peuvent être traités à ce stade.

Ils ne pourraient être traités qu'en vol. Or l'analyse et le résolution des problèmes rencontrés en vol sont très difficiles :

. Limitation en volume de l'installation d'essais embarquée.
. Difficulté d'enregistrer à priori les bons paramètres.
. Interprétation difficile pour le pilote d'un phénomène anormal survenu en vol.
. Difficulté de se remettre dans le même configuration de vol.
. Nécessité de voler à nouveau pour tester une modification.

3.5.3 Essais dynamiques

Pour résoudre les problèmes évoqués ci-dessus, les AMD-BA ont développé une méthode qui a connu ses premières applications dès 1975 sur le programme Super Etendard. Cette méthode utilise le banc d'intégretion précédemment décrit couplé à un ordinateur pour stimuler le système d'armes. La stimulation consiste à remplacer tout ou partie des détecteurs par leurs simulations afin de générer des paramètres cohérents dynamiquement (comme en vol) à l'entrée du système et à entrer dans le système réel le plus en amont possible avec des paramètres physiques primaires -les informations sont alors en nombre limité - et non à des niveaux intermédiaires - où les paramètres peuvent être en nombre illimité.

La stimulation fonctionne à partir de bandes comportant tous les paramètres primaires nécessaires enregistrés de façon cohérente. Les bandes peuvent être soit des bandes entièrement synthétiques, soit des bandes issues d'un simulateur de vol, soit des bandes provenant d'enregistrement en vol sur un autre avion ou sur l'avion d'essai lui-même. L'ordinateur traite ces données de façon à fournir au banc d'intégration les informations correspondant exactement au niveau physique où s'est fait l'enregistrement, c'est-à-dire en général entre les détecteurs et les organes de gestion et de calcul. Les derniers sont donc excités par des paramètres évoluent en temps réel de façon dynamique et cohérente, fonctionnant comme sur avion en fonction des commandes et génèrent les informations correspondantes sur les organes réels de visualisations.

La stimulation permet de faire toute la mise au point dynamique du système indépendemment de l'avion, donc de façon plus rapide et plus économique. Elle permet également de comprendre les problèmes survenus en vol en rejouant au sol autant de fois qu'il le faut la phase critique et en enregistrant tous les paramètres disponibles (bien plus nombreux que sur avion).

Elle permet ensuite de valider les modifications proposées avec le même profil de vol avant de faire un nouveau vol. Elle permet enfin de localiser avec précision l'équipement en cause lorsqu'une anomalie est survenue, ce qui est toujours difficile dans un système hautement intégré.

3.5.4 Rôle du banc d'intégration

Le banc d'intégration est le lieu de passage obligatoire de tout équipement et de toute version de logiciel. Il existe une règle bien précise à laquelle il n'est accepté aucune exception : tout équipement ou toute version de logiciel d'un équipement ne peuvent être montés sur un avion quelconque qu'après avoir été validés auparavant au banc d'intégration.

Le banc d'intégration stimulable intervient à quatre niveaux différents lors du développement d'un système :

- Mise au point et validation d'une première définition de matériel et de logiciel avant vol.
- Etude des anomalies rencontrées en vol.
- Validation des modifications intégrées dans les équipements avant nouveau vol.
- Validation des standards de série avant livraison des matériels et logiciels à la chaîne de production.

3.6 Avion d'intégration

3.6.1 Définition

L'avion d'intégration est un MYSTERE/FALCON XX dont le poste pilote gauche est inchangé mais dont le poste pilote droit est aménagé comme le poste pilote de l'avion d'armes. Dans la cabine, des armoires contiennent les équipements du SNA et une installation d'essais. Un poste d'ingénieur d'essais est prévu avec recopie des visualisations principales du poste pilote droit et accès à certaines commandes de l'installation d'essais et aux simulateurs d'emport.

Le SNA de l'avion d'armes est complet à l'exception du pilote automatique et des contre-mesures. Tous les armements possibles de l'avion d'armes sont simulés par des tiroirs spécifiques avec des commandes à la disposition de l'ingénieur d'essais.

3.6.2 Rôle

Le rôle de l'avion d'intégration est de permettre une première validation en vol du système d'armes avec le double avantage suivant : coût inférieur à l'avion d'armes lui-même et possibilité d'analyse en vol plus fine grâce à la présence à bord de plusieurs personnes. Cet avion permet également une première évaluation des différentes fonctions opérationnelles par les utilisateurs à moindre coût.

3.7 Maquette radio-électrique

La maquette radio-électrique est un avion complet à l'échelle 1/1 équipé de façon représentative avec tout ce qui peut avoir des influences radio-électriques : génération électrique, câblages, structure métallique principale, antennes, équipements.

Cette maquette permet d'évaluer les conséquences radio-électriques du fonctionnement normal du SNA : perturbations dues à la génération électrique, influences des émissions sur les équipements et les emports, diagrammes d'antennes ...

3.8 Chambre anéchoïde

La chambre anéchoïde est capable de contenir un avion d'armes équipé et permet en particulier de mesurer l'influence réciproque des matériels de contre-mesures et leur influence sur tous les autres équipements électroniques et emports possibles de l'avion. C'est à partir des essais effectués en chambre anéchoïde que sont définis les éléments permettant de définir les règles de compatibilité entre tous les équipements de l'avion.

3.9 Avions prototypes

Les avions prototypes forment le dernier élément de la chaîne séquentielle des moyens de développement. Certains prototypes sont consacrés à la mise au point de l'avion lui-même - le moteur, les commandes de vol, les systèmes hydraulique, électrique et carburant - et/ou aux seules ouvertures de domaines des emports envisagés : ils ne comportent donc pas tous les équipements du SNA. Par contre ceux qui sont destinés à la mise au point du système d'armes sont équipés de l'ensemble des équipements et d'une installation d'essais programmable. En effet, le plupart des informations intéressantes circulent sur le digibus auquel est reliée l'installation d'essais. Il n'est pas possible d'enregistrer tous les paramètres du digibus, mais on peut programmer très rapidement la liste d'informations à enregistrer en fonction de l'essai qui va être effectué.

Le rôle des avions prototypes est d'assurer la mise au point finale en vol et dans les conditions réelles d'environnement de toutes les fonctions opérationnelles, d'assurer les vols définitifs d'évaluation des utilisateurs et d'assurer la dernière validation des standards de logiciel série avant introduction sur la chaîne de production.

4 - CONCLUSION

L'organisation du travail de la coordination et la liste des moyens de développement du MIRAGE 2000 n'ont pas été définis en un seul jour : c'est le résultat d'expériences nombreuses. Auparavant des programmes d'avions avec système d'armes moins complexe qu celui du MIRAGE 2000 avaient déjà connu une certaine forme de coordination industrielle en liaison avec les Services Techniques de l'Etat et l'Armée de l'Air. Par ailleurs des bancs d'intégration et plus particulièrement la stimulation avaient déjà été utilisés pour des programmes antérieurs. Toutes ces méthodes ont été élaborées et expérimentées à l'occasion de ces programmes et l'organisation employée pour le MIRAGE 2000 en représente l'aboutissement actuel sous la forme la plus formalisée et la plus achevée.

Ces méthodes de travail et ces moyens de développement ont montré leur efficacité par un nombre réduit d'heures de vol sur MIRAGE 2000 prototype pour aboutir à des fonctions opérationnelles répondant aux demandes des utilisateurs. Il en est résulté des coûts globaux raisonnables et des délais relativement réduits pour assurer la mise au point de fonctions particulièrement complexes dans un système de très haut niveau d'intégration et comprenant de nombreuses innovations techniques, technologiques et opérationnelles.

Ces principes sont désormais appliqués à tous les programmes nationaux de systèmes complexes embarqués dès le stade des avants-projets et de la conception initiale. Pour les programmes export, nous tous industriels utilisons les mêmes méthodes avec cependant un allègement des procédures du fait de l'absence des Services Techniques et de l'Armée de l'Air.

Nous cherchons toujours à améliorer cette méthodologie et deux sujets attirent particulièrement notre attention actuellement :

. La formulation des spécifications de logiciel des équipements. Il s'agit d'un problème général sur lequel de nombreuses étuoes sont en cours à travers le monde entier. A notre connaissance aucune solution totalement satisfaisante n'a encore été trouvée qui réponde aux exigences suivantes : rédaction par une personne connaissant bien la définition du système mais pas particulièrement l'informatique, lecture compréhensible par un non informaticien, analyse exhaustive de tous les cas envisageables, possibilité d'en déduire directement (par des méthodes à définir) le logiciel correspondant, maintenance aisée du logiciel.

. L'extension de la stimulation. La stimulation présente d'autant plus d'intérêt qu'elle permet de faire fonctionner en temps réel un maximum de fonctions des équipements réels. Il s'agit dans ce but d'enregistrer les informations le plus en amont possible. C'est essentiellement pour les capteurs et plus particulièrement pour le principal d'entre eux le radar que le problème est posé. Mais il faut pour cela disposer de matériels embarquables pas trop volumineux et capables d'enregistrer de très grandes quantités d'informations à très haute fréquence.

DISCUSSION

W.Vogl, Ge

What are your plans for mechanisation and to which extent, to establish methods and capabilities for automatic comparison of actually measured parameters with those data theoretically defined or calculated?

Author's Reply

Aujourd'hui il n'y a pas de comparaison automatique entre les paramêtres enregistrés réellement et les paramêtres théoriques utilisés pour la définition. Il n'y a pas de telle comparaison automatique de prévue pour l'avenir, du moins pour un avenir proche.

Crew Station Evaluation in a Dynamic Flight Simulation Facility

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SUMMARY

The Naval Air Development Center is developing a Dynamic Flight Simulator (DFS) which will be used to evaluate Crew Station design concepts in the total G-force environment associated with controlled or uncontrolled flight of high performance military aircraft. The DFS combines the Center's unique human centrifuge with a high fidelity aircraft cockpit, computer-generated visual display system and a digital computer control system to become the world's first pilot-controlled simulation facility capable of reproducing the multidirectional, rapidly varying and sustained G-profiles of actual flight. The DFS will permit the evaluation of advanced aerodynamic configurations, cockpit displays and controls, crew systems and weapon systems in a flight envelope which far exceeds that of in-flight simulation or flight tests. The relative safety of the ~~Dynamic Flight Simulator~~ enables hazardous flight regimes, such as spins and departures, to be investigated in a repeatable, statistically accurate faahion consistent with research and development evaluation facilities.

As an adjunct tc the DFS, the Center operates the Crew Station Evaluation Facility (CREST) to demonstrate and integrate current and emerging control and display technology, and to ensure operator/system compatibility early in the design cycle of Navy aircraft. The CREST laboratory complex is a total Human Factors design and validation facility which, when used in conjunction with the DFS, allows new crew station equipment to be developed and tested prior to dynamic evaluation in the DFS.

This paper will explain the unique capabilities and design of the Dynamic Flight Simulator and Crew Station Evaluation Facility as they pertain to avionics systems development and validation. The NAVAIRDEVCEN considers these facilities as national resources which can be used by the free world's aerospace community to solve today's human interface problems and avoid tomorrow's. It is expected that this capability for pre-flight man-in-the-loop evaluation of aircraft systems/subsystems during early phases of development will diminish the probability of problems surfacing during flight tests and will ultimately reduce the cost and time required for operational deployment.

INTRODUCTION

The Dynamic Flight Simulator, or the DFS, is a manned full system simulation facility which reproduces the total G-force environment common to modern high performance aircraft. Its development was directed by the U.S. Navy's Chief of Naval Material to fill the need for a safe platform to be used in the evaluation of pilot related problems during controlled and uncontrolled flight of military aircraft. The Dynamic Flight Simulator is nearing completion at the Naval Air Development Center and is in its final integration phase with initial operation scheduled for mid-1983.

The Crew Station Evaluation Facility provides researchers with the capability to demonstrate, evaluate and integrate current and emerging control and display technology and crew station designs to ensure operator/system compatibility early in the design cycle of Navy aircraft. The CREST consists of four laboratories: (1) the Interactive Crew Station Simulation Lab (2) the Decision-Making And Voice Technology Experimental (DAVE) Lab, (3) the Computer-Aided Design Lab, and (4) the Static Crew Station Simulation Lab. The laboratory complex is a total Human Factors design and validation facility which allows new crew station equipment to be developed and tested prior to dynamic evaluation in the DFS. The inherent hardware and software compatibility of the CREST and DFS allows a smooth and efficient transition from static mock-up to dynamic evaluation, resulting in a coordinated approach to solving crew station design problems.

BACKGROUND

The need for a total G-force environment crew station evaluation facility has long been recognized. This is particularly critical in programs where rapidly applied, multidirectional, sustained G profiles are involved. Such profiles are generated during air combat maneuvers, missile evasive maneuvers, close air support and weapons delivery and during uncontrolled flight, such as the entry and steady state phases of spin. The excursion and velocity constraints of six degree-of-freedom motion base systems, which are traditionally used for flight simulators, confine their accelerations to the leading portion of a simulated G profile. A number of techniques such as G-seats, G-suits, seat shakers, cockpit dimming, and helmet loading systems have been used as G-cuing devices to complement the limited motion capability of these simulators. As effective as these devices may be in imparting a perception of the G-force environment to be simulator pilot, they do not impart its disabling or possibly its incapacitating effects. These effects can only be produced by a centrifuge-type device or the aircraft itself.

The NAVAIRDEVCEN human centrifuge is uniquely qualified to perform in its role as the motion and force base for the Dynamic Flight Simulator. Originally commissioned in 1952, the centrifuge was upgraded with major improvements to its structural configuration and control system in 1964 and is endowed with a number of outstanding features which have never been successfully duplicated in any other man-rated centrifuge. A number of previous aircraft simulation programs, covering a broad spectrum of flight, have been conducted on the NAVAIRDEVCEN centrifuge. These include: severe air turbulence in a B-720 aircraft; spin simulation of the F-4 and F-14 aircraft; high G with buffet in an F-4; night catapult launching in an A-7; and the emergency descent of a high altitude/multi-mach transport aircraft. Though these programs clearly demonstrated the potential of the centrifuge method of flight simulation, they also identified specific areas which should be improved to achieve this potential. These areas have been significantly upgraded during the development of the DFS, and the centrifuge has now achieved its potential as a full system, total

G-force environment flight simulator.

The Crew Station Evaluation Facility provides a unique opportunity for the integration of hardware, software, and human engineering efforts into the crew station development process. CREST evolved from a previous advanced engineering effort, the Advanced Integrated Display System (AIDS) Program. This program developed two AIDS Simulators, a tandem cockpit and a side-by-side cockpit, which are a major, integral element and capability within the CREST. The AIDS concept consists of providing a laboratory capability for total integration of controls, displays, and software with actual flight capable equipment, such as the AYK-14 general purpose militarized computer, using only a MIL-STD-1553B multiplexed data bus, and a video bus.

Other areas of the CREST, including the Decision Making and Voice Technology Experimental Lab (DAVE), the Computer-Aided Design lab, and the Static Crew Station Simulation lab, are still in the conceptual or system integration phases.

DESCRIPTION OF THE DFS

The DFS is a complete flight simulation facility which can operate on or off of the NAVAIRDEVCEN Human Centrifuge. A block diagram of the overall system is shown in Figure 1. Functionally, the Dynamic Flight Simulator can be broken down into four primary components. The first component is a newly developed multipurpose crew station which contains a reconfigurable single seat aircraft cockpit with active flight controls, instruments and displays. The motion base for the crew station is the Naval Air Development Center's unique human centrifuge which has been proven and refined over 30 years of use. The integrated crew station and centrifuge is linked to a series of computers and their associated control stations which manipulate and transfer the real-time digital and analog data for the DFS. The fourth major component is the NADC Central Computer System which is used to perform the system's aerodynamic modeling and data processing.

Multipurpose Crew Station

The DFS Crew Station is a multipurpose reconfigurable cockpit. It is driven by the simulator control system while in either a ground station/static mode, or in the centrifuge/dynamic flight mode. The cockpit contains a removable cockpit panel assembly, an operational aircraft throttle, a stick/rudder control loader system, an ejection seat and a structurally reinforced, real world, scene generation system (see Figure 2). The cockpit panel assembly is constructed as a removable drawer which can be easily replaced to represent different cockpit designs. The assembly contains active flight and engine instruments, multipurpose full color displays, and a programmable Head-Up Display (HUD). The cockpit has been designed with adjustable down vision, panel width, pilot-eye-to-panel and ejection envelope dimensions which enable it to be reconfigured to closely represent any single seat aircraft cockpit. For additional realism, the cockpit can be independently shaken to simulate buffeting superimposed on the G-force environment.

Visual Display System

The visual display system provides real-time through-the-window scenes representing the outside environment. The system uses virtual image optics with a 48° x 32° field of view. In addition to basic day, dusk and night illumination, landing light illumination, weather effects and moving target images can be simulated. Models of various landing fields, an aircraft carrier and a mountainous terrain scene are currently available. The image update rate is sufficient to give the impression of smooth motion up to a yaw rate of 180°/sec and is synchronized with the aircraft's changes in position, attitude and velocity, for full visual cuing.

Human Centrifuge

The Naval Air Development Center centrifuge is the most powerful three degree-of-freedom, human rated centrifuge in the world. It's unique features include: a 50-foot long arm which minimizes G gradient and Coriolis force problems; a controllable dual gimbal system on the gondola which enables replication of an almost unlimited range of multidirectional G profiles; a 16,000 hp drive motor which provides a 10 G/second onset rate between 1.5 and 15G; a 40,000 G-pound payload capability, which will allow the typical 2,500 pound cockpit and pilot to be accelerated to 15 G's.

The centrifuge's 10-foot diameter gondola is suspended in a controllable dual gimbal system. The gondola is environmentally controlled and contains a 3,000 PSI, hydraulic actuator to oscillate the cockpit for simulation of buffet or air turbulence superimposed on the G-environment generated by the centrifuge.

Experienced engineers control all runs of the centrifuge following well-defined standard operating procedures. A biomedical support team monitors all human centrifuge experiments by instrumenting the subject for physiological data collection. The flight surgeon, along with two other key operators and several automatic controls, can shut down the system to protect both the subject and equipment in case of an emergency.

Data Processing Area

The heart of the real-time simulation capability of the DFS is the Naval Air Development Center's Central Computer System. The system consists of two mainframe central processing units, a CDC-6600 and a Cyber 170, 10 front-end and control processors and a full complement of peripheral equipment. The DFS software performs three major functions for the experiment: full aerodynamic simulation, execution of the centrifuge control algorithm, and data collection and storage. The DFS aerodynamic model has been designed for utmost flexibility when changing from one aircraft to another. Standardised aerodynamic data is accessed via look-up tables in a three-dimensional format so that changing aircraft models can be done without reprogramming simply by accessing a different set of look-up tables. The unlimited data storage available to the system enables entire experiments to be stored and replayed for post run analysis.

DFS Software Modeling

The current DFS control software includes an F-14 aerodynamic data package, a digital flight control system, trim system and the control algorithms for the centrifuge drive, instrumentation, and visual display system. The software generates all aircraft forces and moments using non-linearized equations of motion and three-dimensional data storage for all non-linear engine and aerodynamic data.

The flexibility of the DFS software is particularly apparent in the aero data package. This package is capable of being changed from one aircraft to another without reprogramming and to input asymmetries in mass, engine, or aerodynamic features as required by the experiment scenario. It has no singularities in its earth referenced attitude angles, and permits large angular excursions in angle-of-attack and sideslip.

A distinguishing feature of the DFS in its initial configuration as an F-14 spin simulator, is its ability to fly in the extreme high angle-of-attack (AOA) regime. In this environment, the aerodynamic force and moments typically change very rapidly and unexpectedly with changes in the orientation of the free stream velocity vector. The aircraft may undergo extremely violent excursions so that any state of equilibrium may be simply a very brief transient state. For this reason, the usual linearization of the rigid body dynamic equations is inappropriate and so full non-linear rigid body dynamic equations have been used.

The DFS F-14 aero data package is the same package which is used in the NASA-Langley and NASA-Dryden simulators with the exception that rotary balance data for the F-14 has been added to augment the high AOA regime. The rotary balance data was generated for the DFS by Bihrle Applied Research at the Langley spin tunnel and represents the most complete F-14 high AOA and spin mode data available. This data is expected to significantly improve the fidelity of the planned F-14 Spin experiments.

Centrifuge Control Algorithm

Another state-of-the-art improvement incorporated in the DFS is the implementation of a new centrifuge control algorithm. In the past, the three drive motors of the NAVAIRDEVCEN centrifuge were programmed to provide linear accelerations to a gondola subject without considering the angular artifacts generated while the gondola rotated from one orientation to another. Figure 3 shows the positions of the pilot which are necessary to simulate the various G-profiles. To reduce these angular artifacts and improve the flyability of the DFS, a new centrifuge control algorithm was developed which improves the fidelity of the pilot's perceived angular motions.

The new control algorithm uses the concept of rotating linear vectors to counter-influence the stimuli of the angular accelerations. With this method, the disconcerting angular artifacts can be effectively cancelled out. The new centrifuge control algorithm and the method used to generate it are universally applicable and should be considered in the development and refinement of control algorithms for all motion base systems.

DFS Control Stations

There are three integrated control stations which are manned during all dynamic DFS experiments: (1) the Experiment Control Station, (2) the Centrifuge Control Station and (3) the Flight Deck.

The Experiment Control Station includes a graphics monitor which displays the real-time parameters of the simulation experiment. The ECS is the primary control center for the DFS and acts as the data exchange area for signals going to or from the DFS cockpit and the Data Processing area. The ECS operator has the ability to request and monitor any data necessary to the experiment including mode and control commands to the simulator control system, data base changes, and visual scene changes. A MIL-STD-1553B link to the cockpit enables other 1553B compatible aircraft systems to communicate with the cockpit flight instruments.

The Experiment Control Station contains a graphics display which monitors the real-time parameters of the simulation experiment. Also at this station is the graphics generation hardware for the visual display system, cockpit displays and the head-up display.

The Centrifuge Control Station provides visual and electronic monitoring of the centrifuge operations and includes emergency shutdown controls in the event of a system interruption. Three EAI 231R general purpose analog computers, represent the centrifuge control system. These analog computers, which were previously the only computers used to control the centrifuge, now function to condition and limit digital signals coming from the DFS control system, and to program the drive motors during starting and stopping sequences.

The Centrifuge Flight Deck provides an overall view of the DFS during the operational portion of any experiment. Personnel in charge of directing the experiment are stationed here, including the project officer, the flight director and the medical officer. A biomedical support team is also on duty at this station to continually monitor the physical status of the simulator pilot.

DFS Modes of Operation

Independence of the DFS Experiment Control Station and the Centrifuge Control Station allows the DFS to be used in several modes of operation. In addition to total system dynamic flight operation, the DFS Crew Station station can be used in a fixed base mode for experiments or phases of programs which do not require the force environment provided by the centrifuge. The cockpit instruments and visual display system are driven by the Experiment Control Station to provide any visual or auditory cues required.

As an option, the centrifuge may be used in an open loop mode at any time. In this mode, the centrifuge has no pilot feedback and is programmed to perform a pre-determined force profile upon the subject.

During normal full-up dynamic flight simulation, the Crew Station is mounted in the centrifuge gondola and the simulator control system assumes control of the centrifuge. The pilot then flies the simulated aircraft in a closed loop total force environment.

CREST DESCRIPTION

The Crew Station Evaluation Facility is being designed as a laboratory development tool to be used during exploratory and advanced development integration, and laboratory test and evaluation of crew station/avionics systems. System integration in CREST addresses the incorporation of hardware, software, and human integration efforts into the system development process.

The three major advanced technologies which can be evaluated in CREST are Displays, Flight Control Integration, and Human Factors Engineering. The interrelated but distinct requirements of each of these technologies defined the equipment configuration of the CREST laboratory complex. The floor plan of the CREST laboratory is shown in Figure 4.

Interactive Crew Station Simulation Lab

The two AIDS cockpits which represent the primary staging area of the CREST, along with their external view projection systems, are located in the Interactive Crew Station Simulation Lab.

Tandem Cockpit: Controls/Displays

The tandem cockpit contains six reprogrammable multipurpose displays, four in the front seat and two in the back, an active side-arm controller and a generic throttle, a voice recognition system, and a helmet-mounted display system (see Figure 5). A simulated Head-Up Display (HUD) is projected on a 7-foot TV projection screen approximately 12 feet in front of the cockpit. Video tapes, simulation models, or scenes from a terrain model board can also be projected on the screen to represent a real world scene while simultaneously presenting HUD symbology.

The Vertical Situation Display (VSD) located in the center of the front seat cockpit panel is a raster display which presents either flight control or sensor information. The VSD flight display is similar to that of the HUD and either may be used in case of an equipment malfunction. The VSD can also present sensor information from radar, low-light level television, or television camera guided missiles.

The Horizontal Situation Display (HSD), located directly below the VSD, is a raster display which presents both tactical and navigation information. It may also be used as a backup for the VSD. The HSD, depending on the mission mode, may show a minimum time curve for ascent, a compass rose with heading commands, aircraft and target symbology, a moving map, and numeric readouts for time, position, communications channels, and fuel data.

The Right Situation Advisory Display (RSAD) is a stroke display which presents general aircraft system monitoring information in an alphanumeric format. The Left Situation Advisory Display (LSAD) is a stroke display which presents either engine management information or weapons status information. As with the VSD and HSD, either Situation Advisory Display may be used as a backup for the other.

Pilot actuated switches are contained in two sets of touch sensor controls. The Mission Mode Controls (MMC) are a set of 16 buttons used for determining display formats for various mission segments such as preflight, climb out, dash, or air-to-air. The Integrated Control Set (ICS) is a group of 43 buttons and a forcestick used for determining the type of mission to be flown, where displays are to be shown and what information will be displayed, numerical inputs to the computer, and general pilot/computer communications.

The flight controls include a side arm controller, two throttles, and 15 auxiliary switches including engine, flight, and weapons controls. Also included are vocally actuated switches.

The aft crew station contains a raster display which duplicates the front seat information and a Tactical Information Display (TID) which has not yet been activated.

Side-by-Side Cockpit: Controls Displays

The side-by-side cockpit is currently being integrated into the CREST. When completed it will contain six three-color general purpose raster displays driven by a raster symbol generator. Side arm controllers and throttles are provided for both the left and right pilot stations. The side-by-side cockpit utilizes a real-world scene and HUD projection system similar to the one used for the Tandem Cockpit.

Cockpit Control Computers

The computers which currently control both cockpit simulations are a NOVA 820 and a NOVA 800 minicomputer. The computers are located in the Electronics Bay Area of the CREST. The NOVA 820 functions as the I/O (input/output) controller for the cockpit displays and controls. The NOVA 800 performs the required functions on the I/O data, which the NOVA 820 receives and sends to a 6007 Disk Emulator. After the NOVA 800 performs the required processing, the data is sent back to the Disk Emulator where the NOVA 820 reads it and performs the required output function, e.g., data update for the displays. The NOVA 820 and 800 both have 32 K memory and are programmable in FORTRAN.

Two Programmable Display Generators provide the symbology for the various cockpit displays. A separate Programmable Signal Generator provides the symbology for the HUD. Voice interaction capability is provided by a VOTRAX multilingual voice synthesizer for audio cues signifying mode changes, malfunctions, and various advisory situations and a Threshold Voice Recognition System which provides a 190-word branch control capability.

As shown in Figure 5, the CREST cockpit simulation system has access to various peripheral hardware components: 3 Disk Packs, console, console printer, paper tape reader, and a paper tape printer. A PDP-11 with 96K memory is interfaced with the NOVA 820 via an RS-232 serial data bus. Eventually the PDP-11 will assume the control functions of the Interactive Crew Station Simulation lab, although it is presently used to generate software to be run on the NOVA 820. An AYK-14 computer is likewise scheduled for integration.

Terrain Model and Target Generator

CREST also includes a Gantry-Terrain Model and a Target Generation System. The Gantry-Terrain Model is located as shown in Figure 4 and includes a vertically mounted 22' x 36', 2000:1 scale, color terrain board. The servo-optical probe, capable of three degrees of motion, is operated via the gantry and provides input to a high resolution TV system which can display the scene on TV Projection Screens in front of the CREST cockpits. The terrain board is illuminated via a bank of fluorescent lamps on the opposite wall.

The Target Generation System (see Figure 4 for location in CREST) consists of a stationary TV camera aimed at two models of a particular type target aircraft, control/drive equipment and a computer interface. One of the models is mounted by its tail, the other by its nose. The models can be rotated about the three axes so that each aircraft provides half of the sphere of all possible target aspect angles. Together, the two target models can create a target image in any orientation which is overlaid upon the external world scene on the TV projection screen. The aircraft models which are currently available are an A-4 and an MIG-21.

Decision-Making And Voice Technology Experimental (DAVE) Lab

The DAVE laboratory provides the capability to develop and evaluate new man/machine interfaces and to establish design criteria for advance technologies such as "Smart" operator decision aids and speech recognition/synthesis. The development of design criteria is based on objective operator performance data collected from simulation studies of the new interface concepts within the DAVE laboratory. The DAVE simulation capability delivers reliable and valid data, which can be directly utilized by the system engineer. The DAVE Lab is in the process of being interfaced to the NAVAIRDEVCEN Central Computer system. Once this is accomplished, all real-time simulation will be performed on a CDC-6600/Cyber 170 mainframe. Input/output data from the CDC-6600 will be utilized by the following equipment, which is resident in the DAVE lab: (1) Chromatics Color Graphics Display system, (2) Lambda LISP Processor (3) Lear Siegler Airborne Voice Recognition/Synthesis System and (4) Group Decision aid Model 1011.

Computer-Aided Design Lab

The Computer-Aided Design Laboratory offers the capability of using computer models for the design and evaluation of aircraft crew stations. These computer design models developed at NAVAIRDEVCEN enable system engineers to determine the impact of existing and emerging control/display technologies on crew station configurations and operator performance. The Computer Aided Design lab has access to a library of computer models such as: the Crew Station Assessment of Reach Model (CAR), and the Human Operator Simulator (HOS) model, all of which are available to support work done in the lab.

Static Crew Station Simulation Lab

The Static Crew Station Simulation Laboratory is specifically designed for Human Factors and engineering evaluations of static mockups for any Naval aircraft and for the development and evaluation of crew station lighting. This laboratory offers reconfigurable mockups with the capability of geometrically representing any current or future single seat, tandem, or side-by-side crew station. In addition, the Static Crew Station Laboratory has the capability to evaluate new aircraft lighting technologies and to conduct lighting studies leading to improvement of outmoded crew station lighting specifications. This lab is still in development.

DFS/CREST APPLICATIONS

DFS Functional Capabilities

The Dynamic Flight Simulator has brought the art of flight environment simulation to its ultimate form. This is by virtue of its versatile and precise aircraft dynamic modeling, coupled with realistic motion, audio, vibratory and visual cues and a full scale acceleration field. While the DFS capabilities are most applicable to the exploration of those "edge-of-the-envelope" conditions, which often pose a hazard to the aircraft and crew in actual flight, it is equally useful as a conventional motion base simulator in benign flight conditions.

The Dynamic Flight Simulator can be used by both government and industry as a flight research facility available at any stage in an aircraft's development cycle or during its operational life. Often times during operation, problems arise which have not been uncovered in the development cycle. Usually these are the results of unexpected natural phenomena or penetration into flight regimes not previously predicted or accurately tested. The Dynamic Flight Simulator provides an earth-bound, laboratory environment where these situations can be safely explored prior to flight validation.

The Dynamic Flight Simulator's utility in solving existing problems ranges from the development of piloting techniques for recognizing, avoiding, or correcting departure or spin conditions, to the preflight investigation of engineering changes designed to correct flight deficiencies or undesirable flight characteristics.

Past applications of the DFS/Human Centrifuge have concentrated on such problems as pilot disorientation and reaction during night catapult launches from aircraft carriers, uncontrolled spinning flight of high-performance aircraft, and clear-air turbulence encounters by jet transport aircraft. In each case, the insight gained through these experiments have led to better pilot recognition and interpretation of the onset sensations as well as confidence in applying corrective control.

In a similar vein, the DFS can be employed to investigate high angle-of-attack flight, post-stall gyration, air-combat maneuvering and low-altitude terrain following flight. Potentially hazardous pilot-induced oscillations associated with high-speed flight, landing approach and special situations such as mid-air refueling, are other problems which can be safely addressed in the DFS.

As a problem avoider, the Dynamic Flight Simulator offers the opportunity to investigate these and other flight conditions in advance of the "bending metal" phase of aircraft development; during the period when design changes are relatively inexpensive as compared to changes to correct deficiencies uncovered during flight test. The art of aerodynamic prediction through wind tunnel testing and numerical analysis makes data available of sufficient quality to allow all but the most subtle aerodynamic characteristics to be accurately modeled and the resultant flying qualities and handling characteristics to be investigated.

The DFS offers a wide range of applications as a result of its unique capabilities for dynamic crew station simulation. Several of these applications are listed below:

- Total Systems Simulation
- System/Subsystem Design Evaluation
- Crew Station Design
- Human Factors Engineering
- Procedures/Tactics Evaluation
- Spin Simulation
- Flying Qualities
- Specialized Training
- Accident Investigation
- Acceleration Research

The DFS can be used to evaluate pilot performance and transfer of training in high stress or hazardous flight scenarios. In this area, the DFS can in fact safely exceed the performance of flight testing.

The expanded flight regime available in the DFS is graphically portrayed in Figure 6. The curves in 6a and 6b show the acceleration environments associated with the spin of a typical aircraft. These graphs of acceleration versus yaw rate, indicate that the DFS is capable of operating safely in a flight envelope encompassing the full regime of the spin. Duplication of this envelope is not available in any other ground based simulator and far exceeds the limits of a safe flight test which is shown in the left hand corner of the graph.

Planned DFS Programs

The first program scheduled to use the full system capability of the DFS is a U.S. Navy sponsored F-14 Flat Spin Investigation program. The DFS Spin Program, scheduled for the late 1983, will investigate pilot related problems incidental to aircraft stall/departure, spin entry, and spin recovery. Of concern is the degree of pilot incapacitation, pilot disorientation or confusion, and excessive pilot work load at a critical time when a delay in his being able to recognize the true situation and execute the proper controls can result in the loss of the aircraft. Parametric variations will be made in the pilot restraint system, the cockpit displays, and the delay in pilot execution. DFS pilots will be required to perform realistic control tasks in the spin environment while their success rates are statistically tracked.

The outcome of the experiment is expected to uncover potential areas for improvement in the design of the F-14 controls or displays with regard to spin warning or recovery systems.

Follow-on DFS programs will involve spin studies for other aircraft and evaluation studies of new systems/subsystems for current and future military aircraft during all stages of their development. The DFS is projected for use for specialized flight training for high G and hazardous flight regimes and for out-of-control flight situations. It will also be used as an aid in certain accident investigations to recreate the actual flight environment which preceded the accident in order to determine what effect the environment may have had in preventing the pilot from executing the proper controls.

CREST Functional Capabilities

Functional capability of the CREST laboratory is presently limited to the Computer-Aided Design Lab, DAVE lab and Interactive Crew Station Simulation lab. Using the tandem cockpit, various mission flight scenarios have been run. The simulated missions have consisted of the following phases: preflight, systems check, mission data input, checklist for take-off, engine start sequence, take-off/climb, dash/loiter, an air-to-air engagement, return to base/landing, and postflight. Other components of CREST are in the system integration phases with full-up operation planned for 1984.

CONCLUSIONS

The DFS has opened up a new dimension in flight simulation by providing a flight environment heretofore unavailable to the ground-based simulation community. A wide spectrum of aircraft systems/subsystems can now be evaluated under pilot control with the authenticity of a flight test and the safety, repeatability, and convenience of a simulator.

The combination of the powerful NAVAIRDEVCEN man-rated centrifuge with real-time, man-in-the-loop aerodynamic simulation and a high-fidelity crew station provides a unique capability unavailable on other motion-based simulators. No other ground based system in the world can offer the realism of the sustained G-forces of true flight. The DFS can provide a platform for testing and training in a safer and more economical environment than that of in-flight simulation and flight tests.

As national facilities, both the DFS and CREST will provide the Tri-Service, foreign, and industrial communities with platforms for evaluating new concepts in crew station design, crew equipment, restraint systems, and flight controls. As human factor tools, the DFS and CREST will be used to evaluate pilot performance and transfer of training in both hazardous flight regimes or benign environments. The pre-flight man-in-the-loop evaluation of aircraft systems/subsystems during early stages of development will help to diminish the probability of problems surfacing during flight T&E and substantially reduce the cost and time required for system development.

The Naval Air Development Center is offering the use of the DFS and CREST to the entire aerospace community. In doing so, it makes available a full system development facility which has not previously been available for the classical Research, Development, Test and Evaluation cycles of military and commercial aircraft. As a newly developed capability, the full potential of the DFS/CREST is just beginning to be realized. Interested users are invited to consider their application to the solution of present crew station design problems, and to be imaginative in applying these facilities to future problem avoidance. A full spectrum of options are available for users. Programs can be run entirely by NAVAIRDEVCEN engineers who will plan, conduct, and report on the test, or the user's own personnel can participate in the design, testing, and data acquisition efforts associated with their programs. NAVAIRDEVCEN is aware of the need for some users, especially those in the foreign and industrial communities, to protect the results of their proprietary research and development activities and is prepared to ensure the security of any tests which are performed. The Naval Air Development Center recognizes that the need to assist users of the DFS and CREST will vary with their desires for privacy in their work and their need for assistance. In either extreme, the combined resources of the NAVAIRDEVCEN are available to assist in the planning and operation of any type of experiment.

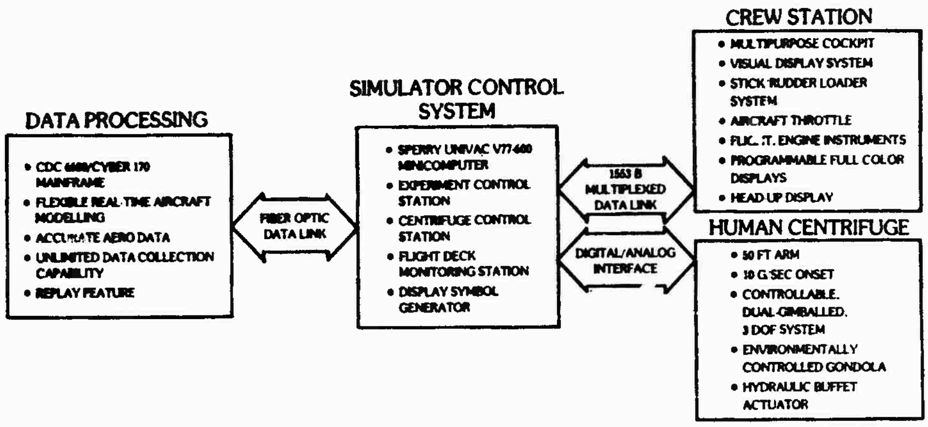


Figure 1. Block Diagram of the Dynamic Flight Simulator (DFS).

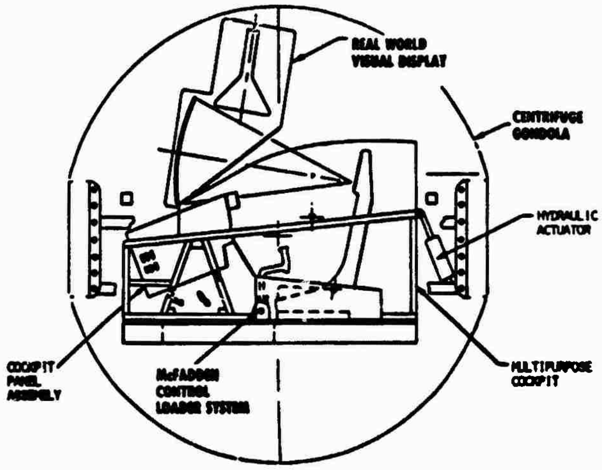


Figure 2. DFS Crew Station Installation in the Centrifuge Gondola.

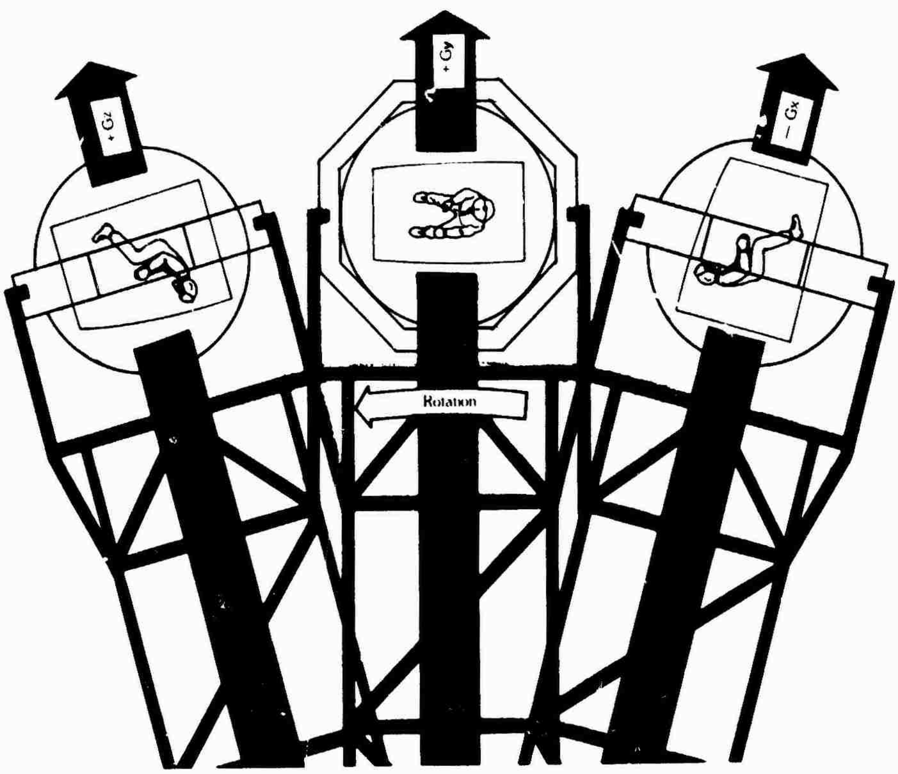


Figure 3. Developing the G-Vector in a Dual-Gimballed Centrifuge

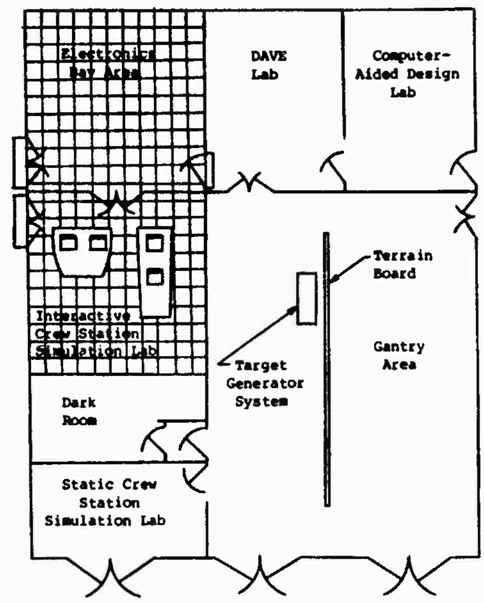


Figure 4. Crew Station Evaluation Facility (CREST) Floor Plan

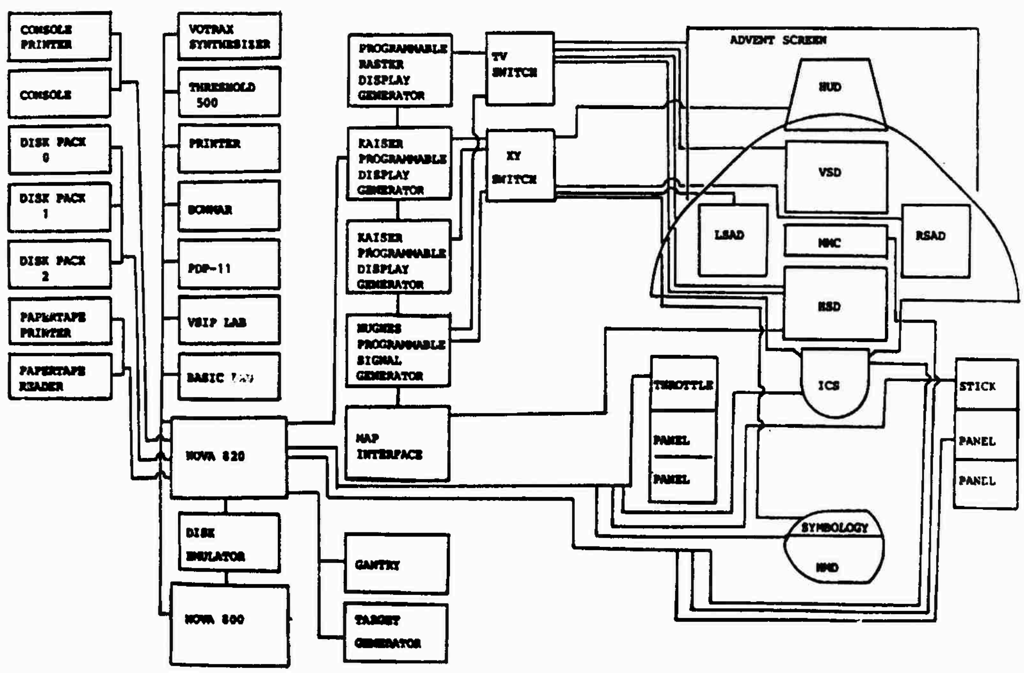
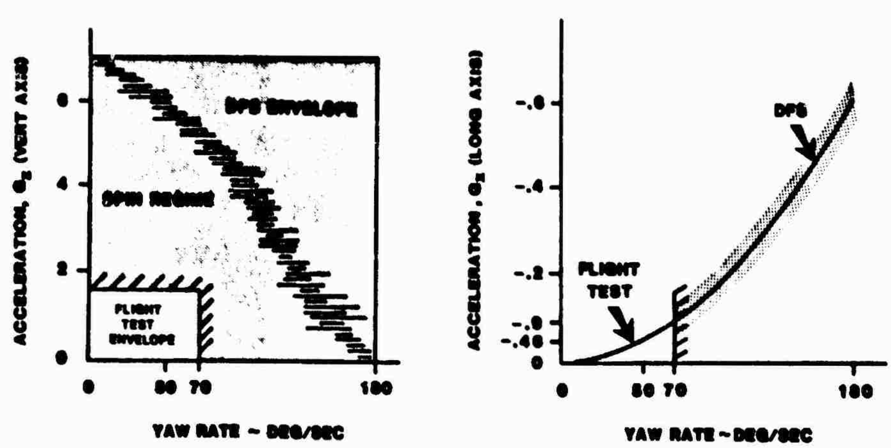


Figure 5. CREST Tandem Cockpit Controls/Displays Block Diagram (Front Seat Only)



a) Gz (Seat-of-the-Pants) vs. Yaw Rate b) Gx (Eyeballs-Out) vs. Yaw Rate

Figure 6. Acceleration Environment Associated with an Aircraft Flat Spin

DISCUSSION

J.P.Murgue, Fr

Have you any result about the maximum g's condition which a pilot is capable to stand whilst operating a Helmet Mounted Sight?

Author's Reply

We have not tested a Helmet Sight in our centrifuge although the airforce has done HMD tests in the past. A program to test the new HMD technology in the DFS would be welcomed but has not as yet been planned.

K.F.Boecking, Ge

Can you say something about the costs per flight hour?

Author's Reply

The cost algorithm is still being developed. It is expected to be competitive with other "moving base" flight simulations.

G.Hunt, UK

Is it your intention to validate the high-g simulator by measuring pilot performance, under similar acceleration conditions in an aircraft and in the simulator?

Author's Reply

The current validation effort is comparing actual F-14 flight test data to the simulator in the level flight and high angle of attack regimes for both high and low g manoeuvres. Spin test data will be compared as far as it is currently available. Other data has been developed using wind tunnel tests.

W.H.McKinlay, UK

Is there any practical limitation as to the rate at which g can be applied for example in transient manoeuvres?

Author's Reply

The centrifuge is capable of a g-onset rate of 10 g's per second which is sufficient to simulate most high performance aircraft. However, the aerodynamic model of the particular aircraft will regulate the actual onset rate to match the desired manoeuvre.

F.W.Broecker, Ge

What kind of parameters (technical or human) are mainly recorded in your centrifuge?

Author's Reply

The simulator can record all aerodynamic parameters which are used in the software model and most of the pilot performance parameters medical data is also monitored for safety reasons.

J.Vaillancourt, Ca

Do you simulate the air refuelling function? If so how do you super-impose the refuelling tanker video onto the SP-2 Rediffusion display?

Author's Reply

It is not implemented now. A tanker "CGI" model is available for the SP-2, however, it would probably not be economical to use in the centrifuge since "G" is not a problem parameter for this type of mission.

Concepts for Avionic and Weapon Integration Facilities

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ABSTRACT

The Tornado avionic and weapon integration facility at MBB-Munich, which was upgraded in the recent years, is presented in detail. The increased test capabilities are pointed out. Requirements for future integration concepts and the according ground test facilities are given.

1. INTRODUCTION

In developing Aircraft Weapon Systems with complex avionic equipments, the designer is faced with the difficult task of how to adequately validate the system in a realistic environment before committing it to a series of missions. In most cases it is either too expensive, time consuming, or the risk factor is considered too high to allow an exclusive series of flight tests. Thus appropriate ground test facilities are required.

In general a flying weapon system consists of hardware, software and some non-avionic systems designed together to meet the required mission abjectives. In the design process the flight hardware components are developed seperately by different organisations using a common set of requirements. Similarly the flight software is coded to meet the associated software requirements. Finally hardware and sofware are brought together on the ground in an environment which enables system checkout and integration, the so-called "Integration Rig". The rig-design should provide computer aided real-time simulations of the airborne conditions at different levels. Only when the ground operated system is subjected to the same dynamic conditions as on a mission are significant validation tests possible, and thus the goal of avoiding or reducing flight tests may be realised.This paper will attempt to show on the basis of experience with the Tornado development phase what can be achieved today in this direction.

2. TEST METHODS FOR THE TORNADO DEVELOPMENT

The main features of the Tornado Weapon System to Avionics are:
- the highly integrated precise navigation system
- the terrain following system
- the central mission Computer which performs all navigation, steering, weapon aiming and delivery computations
- the digital armament control system.

To achieve this it was necessary to install a complex avionic system with a reasonable interaction to nonavionic systems wich are critical with respect to flight safety. Thus a test and integration concept was selected with emphasis laid on ground based facilities. The Concept was comprised of five levels partly overlapping in time:

Stage 1: Development and approval tests for Mission Computer software. The software, coded and assembled with the aid of a main frame host computer, is loaded and run on a Mission Computer which is connected to a minimum of avionic- and selected test support peripherals.

Stage 2: Basic equipment integration of development models and verification of flight software under laboratory conditions by means of a basic test rig.

Stage 3: These tests are the so called carrier aircraft or flying test bed trials, carried out on major subsystems including Navigation and Radar, expecially with respect to the terrain following capability.

Stage 4: Tests carried out on complex test rigs designed to support system integration and validation as well as performance trials wherever possible on the ground. The avionic subsystems are connected, integrated step by step and operated with flight software in an aircraft like environment, which in common is conveyed to the system via sensor output data and includes interaction with non-avionic systems.

Thus the adequate rig should comprise at least simulation equipments, by which the sensors can be modelled and substituted. For more comprehensive tests however, it is necessary to include the sensors in the ground operated system by stimulating them directly or inserting the desired data near their point of origin within the sensors.

The stage 4 avionic rig at MBB, upgraded in the recent years, now including the weapon system, many 'front-end-sensor-stimulation' devices, a signal link to the flight controls systems (located in a separate rig) and a new data handling and simulation system meets all requirements of this test-level. This facility is described in the next paragraph in more detail.

Stage 5: Flight tests with prototype aircraft. The idea of this level is to give final performance verification trials, not to support extensive fault detection and correction.

3. THE MBB INTEGRATON AVIONIC/ARMAMENT RIG AND RELATED FACILITIES

The rig is designed to support the following tasks:

- o Hadware integration. Basic electrical integration testing ranging from the individual equipment level through all intermediate sub-system levels up to the whole system. Tests under static and dynamic signal conditions.
- o Software/hardware integration. Verification and validation of mission computer software in conjunction with the real flight hard- and firmware under mission representative conditions.
- o Integration of the avionic/armament system with other related systems, e. g. Autopilot Flight Director Flight Control System or the aircraft power supply.
- o Confidence and performance testing. These class of tests are considered essential for the sub-systems involved in Terrain Following (TF).
- o Investigation of the effectiveness of the man-machine interfaces
- o Basic EMC studies.
- o Support of flight tests, i. e. crew familiarisation with test procedures as well as test data preparation and evaluation.

In the near future, when the initial development phase is concluded the following tasks are anticipated, since the rig has recently been upgraded to the a/c production standard:

- Back up facility for fault verification, investigation and correction
- Hardware/software development support for future upgrades/modifications to the Tornado, for example adaptation of new weapons or ECM-devices.
- performance studies for modified or new mission types.

The resulting structure of the test facility has a central section comprising the avionic and weapon components, including the cockpit area and several special to type test-equipment/simulators which may be connected to the central rig or operated independently (Figure 1). These special test facilities can serve as front-end stimulation devices for the sensors they are built for. They are remotely controllable by a medium size digital simulation facility - which incorporates extensive data acquisition and reduction tools - or by a big high-fidelity simulation. The simulations differ in complexity, availability and also expense in both the direct and indirect sense.
Other important aircraft systems are concentrated in separate but connectable rigs, namely the flight-control systems rig and the electric-system rig.

In the following a brief description of all parts forming the test facility is given:

3.1 The main Test Rig.

The central part of the rig represents a simplified copy of the front airframe including the cockpit. The avionic equipments, the autopilot and cockpit control elements can be installed in their original mounting trays and are connected by aircraft cabling.

To access signals internal to the avionic and/or weapon system system all important devices may be operated external to the central rig on dedicated collocated test and 'patch' panels. These panels are designed to either work as a stand alone test facility with proper simulation equipment, or as an integral part of the overall Avionic/Armament-system.

In the same way the following additional special to type test equipments/simulators can be operated with their sensors, providing a manually or computer controlled front end or nearly front end stimuation:

- o Turntable for gyro-stabilized sensors providing variable attitudes.
- o Pressure transducer stimulator for the Air Data Computer
- o Doppler-, Radio-Altimeter and Tacan-stimulators

- o Radar test bench with an absorbtion chamber, a target simulation for the ground mapping radar and a terrain simulation for the TF-radar controllable only by the MBB-UF simulation centre (see Fig. 2)

- o IR-Target-simulation for the A/A missile.

In addition to the above devices an ECM test facility and a self-contained special stand alone tester for mission computer hardware/software should be mentioned for completeness.

The cockpit is equipped for the two crew members with the following man-machine interfaces:

- o Avionic and Weapon Controls, Keyboards and Indicators

- o Displays for the Radar, the main computer, the Head Up Display and the TF-display (E-Scope)

- o other indicators and flight controls, i.e. stick, throttle levers, pedals, wing sweep lever, which are necessary to fly the a/c manually.

Five main parts of the weapon system are now integrated in the rig

- o the Stores Management System including the gun electronics unit

- o Air-to-Ground Missile System for the anti ship missile Kormoran

- o Air-to-Air missile system for the Sidewinder.

- o Special Weapon System

- o MW-1 (under contruction)

3.2 Flight control systems rig

As a further approach to the goal of testing all devices chained by interactions a signal link to the flight control rig was installed in 1981. This rig comprises in an a/c-like assembly the primary and secondary flight control systems, i. e. the Command and Stability Augmentation System (CSAS) with the related air data sensor, the rate gyros, the actuators for the aerodynamic control surfaces like rudder, "taileron", flaps, slats etc. Additionally it provides an alternative operation capability for the autopilot and has a cockpit equipped with controls and indicators necessary for human guided/monitored flights. Several auxiliary systems like the hydraulic pumps or the air intake control system are integrated.

Thus - when connected to an appropriate simulation - this facility enables detailed investigations of the flight control system. A special computer simulation of the aerodynamic loads applied to the control surfaces is noteworthy, enabling investigations of the failure probability of critical systems by long endurance tests.

3.3 Electric systems rig

Another connection of the Avionic/Armament rig is installed to the electric-systems rig. The a/c generators, transformers, the battery and the power control unit form part of this facility. The important influence of the on-board power-supply-system on the aircraft electronics i. e. voltage transients, ac-frequency changes and interruptions of power which may generate errors can be investigated with this rig.

3.4 Computer aided data acquisition/reduction and simulation

The quality of the test facility is determined by the computer aided tools, which are provided here at two different levels: one for multi-purpose applications and simple simulations, called IDAS, and one for complex high fidelity simulation of the aircraft behavior under arbitrary conditions. The smaller system is dedicated to the avionic/armament rig, while the greater system is concentrated at the simulation center MBB-UF and is shared by several users.

3.4.1 The Integrated Data Acquisition and Stimulation System

The completely renewed IDAS-System consists of a software package and standard minicomputers (PDP11) with appropriate signal converters. The handling is based on normal plain English and does not require the knowledge of programming languages. It enables the user to:

- o Acquire data from the avionic/weapon system under real-time conditions and record them onto magnetic tape/disc for subsequent off-line reduction or later re-injection into the system. For convenient data evaluation and replay additional user written Fortran-routines are linkable. Data acquisition may also include values internal to the operational flight software, wich are retrieved via special test outputs of the mission computer.

o stimulate parameters statically by predefined, repeatably callable sets of data.

o dynamic data injection and remote control of the sensor front-end stimulation. The avionic/weapon system data, especially the sensor outputs can be substituted partially or totally. Another possibility to control system data is given by the remote steering of the special to type test equipment/simulators. Data sources may be recorded files from either rig- or flight test equipment, or may originate from evaluation of simple mathematical formulas.

For example if the test conditions require an ascent of the aircraft with constant climb angle and velocity, an IDAS-testprogram can be prepared, calculating the increasing heights from the Air Data Computer and the Radio Altimeter with the correct time dependency.

On basis of the formula evaluation capability a simplified, low-cost aircraft model has been provided, allowing a 'flight' with the avionic and armament systems manually controlled via cockpit controls or guided by the autopilot. The approximation level of this simulation is sufficient for basic tests and also crew familiarisation with respect to avionic tasks and weapon delivery moding.

o define events and automatic actions. The test execution can be based on time with a maximum action-rate of 1 KHz or on reaching predifined data values or conditions. If e. g., the data recorded during flight test are to be injected in a system-configuration, the data stream can be started some minutes after take-off and above a specified height reached during flight.

o reference all values which form part of the avionic input/output by a name; a central avionic data file keeps all scalings and restrictions giving a unique description of the referenced variable by which it is handled by the software automatically. One of the most important features of IDAS is a program which supports the generation of avionic data file-versions belonging to different flight hardware and software configurations. So investigations including various modification levels of avionic/weapon systems are easily performed.

o load versions of operational flight software in the mission computer. Down load of flight software or special system test programs is supported.

The hardware basis is formed by two DEC PDP11/60 computers connected by an interprocessor link and equipped with standard peripherals like discs, magnetic-tapes, video/paper-terminals and a plotter.

Additionally special interfaces are integrated giving access to

- analog signals (voltage levels)
- 5 types of discrete signals
- Tornado serial signals
- Mil-Std-1553B signals- and bus-protocol
- PCM-Signals as used by Flight test equipment and Crash Recorder
- steering signals for the special to type test benches/simulators

3.4.2 The simulation centre at MBB-UF

At this centre various high fidelity real-time simulations are available. Here three special programs driving hardware in the loop rig-tests are of interest.

The basic computing system consists of a Rank Xerox Sigma 8 System, which is replaced now by DEC's VAX11. Interfaces and programs are provided for following main configurations:

o Digital Simulation connected with the avionic/armament rig: The software synthesises in real time the fly-by-wire system, the engine and the free flying aircraft in 6 degrees of freedom. On basis of approximately 70 000 coefficients nearly all configurations (wing sweep, center of gravity, flap setting etc.) of the Tornado can be modelled.

Inputs to the programm are cockpit or autopilot commands from the rig, outputs to the rig are values describing the aircraft state of motion and attitude formatted as sensor-outputs, e. g. from IN, ADC or Doppler System. Where it is necessary, front- end sensor stimulation is possible by the remote control of the special to type test benches/simulators.

o Digital simulation connected with the flight control systems rig: Similar to the previous case the airborne environment is simulated as far as necessary for the flight control systems. Especially the aerodynamic loads are calculated and applied via hydraulic counteractuators to the flight control mechanics.

o Digital Simulation connected with the linked Avionic/Weapon - and Flight Control System rig:

This represents the most powerful hardware-in-the loop configuration. The airborne environment is exactly simulated in the relevant variables for a ground based system comprising the avionic/weapon-devices, the autopilot, the CSAS and the hydraulic/mechanic components of the flight control system.

In the following chapter a system test is described concerning the automatic terrain following mode to convey an idea of the capabilities of the above configuration.

3.5 Testing the Tornado-terrain-following mode as an example

In order to achieve operational clearance for the Tornado IDS automatic terrain following system comprehensive rig tests where necessary, before flight testing could start at low levels. Test objectives where to give an essential contribution to the performance trial, to investigate failure consequence and the effectiveness of warnings. Briefly the tests aim at creating confidence in the system.

The TF-System controls the flight path of the aircraft to a preset clearance height above the terrain. A terrain following computer generates a theoretical ski-toe shaped envelope in front of the plane and compares it with radar returns from ground. If at any point terrain is found to penetrate into the envelope, an automatic pull up command is generated and passed to the autopilot. Figure 2 shows the structure of the system, its partitioning on two rigs and the signal-flow with loops closed by digital simulation.

Within the Sigma 8 the free aircraft is modelled. The resulting attitude and location of the airplane is sent to a fast processor (miproc 16), which calculates in real time the radar range with respect to a prestored 3 dimensional terrain and also on the basis of scan and azimuth angles received from the rig-operated real antenna. According to this range a delay generator is remotely controlled, simulating the pulse timing for the radar. Fig 3 shows the comparison of a real flight path and a rig-simulated one under the same conditions. The flight data was available via magnetic tapes recorded by flight test equipment. Derived from these a two dimensional actual overflown terrain was reconstructed by subtracting the measured radar altimeter height from the corrected barometric height. This terrain was fed into the simulation and again "overflown" with the rigs. The small mismatch between the flight paths is within acceptable tolerances. Thus the built up hardware in the loop simulation gives significant results for failure consequence and performance tests.

4. TEST CONCEPTS FOR FUTURE AVIONIC/WEAPON SYSTEMS

Basicly the Tornado test concept came up to the expectations, however, same points we learnt are noteworthy and should be taken into consideration for future developments.

(a) Well equipped test rigs comprising as many as possible of the relevant aircraft systems reduce development time, cost and potential risk. Such a rig should have a modular structure with growth potential to support all phases of development including upgrades/modifications during the in service phase of the flying weapon system. These tasks are only supported effectively if the ground test support and simulation tools share attributes mentioned in the following two points.

(b) A homogeneous support software/hardware system should be used for testing the flight software, integrating the hardware and preparing/evaluating data from flight tests. It should be connected to a data base of the avionic/weapon system which is common to all activities. This data base should be defined and implemented as early as possible in the development phase, thereby enabling configuration and compatibility control, and so eliminating a main error source.

(c) Software modifications, i. e. fault corrections, upgrades and adaptations to system changes, are eased dramatically if a relevant and sufficient documentation exists. The creation of effective documentation is supported, if a modern computer aided software development tool and, if possible, a high order programming language is used.

(d) For economic reasons it is necessary to provide a wide spectrum of simulation-, stimulation and substitution facilities. The most powerful configuration is required rarely, the less complex ones more frequently.

(e) The avionic and weapon systems shall provide a wide access to internal data to increase the testability. For rig testing avionic/weapon units should be available allowing a replacement of processor-chips by connections to external real time simulators (emulators).

The following brief summary describes a future levelled test concept.

Level 1: The software development for the mission computer and the test support tools is performed on a host by means of computer aided tools and by employing a high order programming language. A data base describing the software modules and their interfaces is installed. This data base has sufficient growth potential and is common to all development tools and phases. The software test is carried out by using emulator devices for the target computer with sophisticated trace and fault detection capabilities.

Level 2: The basic integration of equipments as well as the hardware/software integration is performed on a rig, which has a structure and a growth potential allowing an upgrade to the level 4 without redesign.

Level 3: Flying test bed investigations can be onmitted generally but may be useful in special cases, provided the characteristics of carrier aircraft sufficiently resemble the aircraft under development.

Level 4: System integration, validation and performance trial are carried out as far as possible on a well equipped rig facility comparable to the one presented in this paper. This level is the focal point of all test activities. The general intention is to detect and correct all errors and specification mismatches before entering flight tests.

Level 5: Flight test on prototypes for final performance trials only.

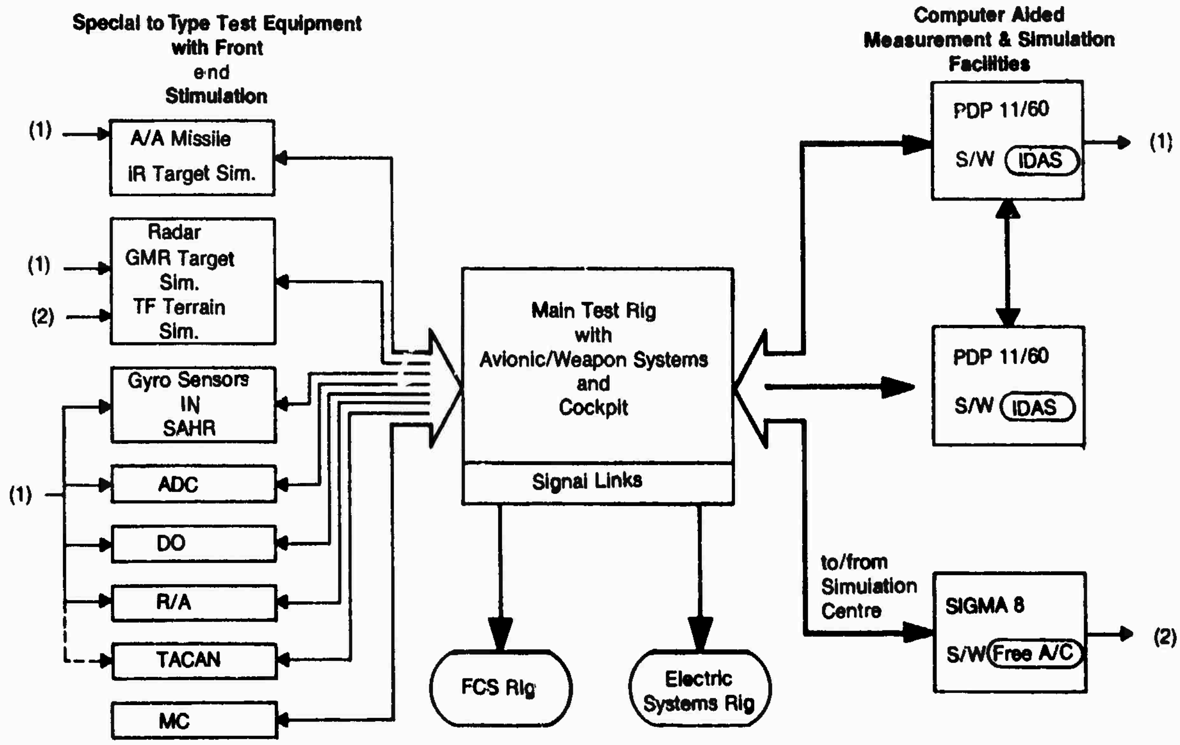

Figure 1: Structure of the Avionic/Weapon Integration Facility

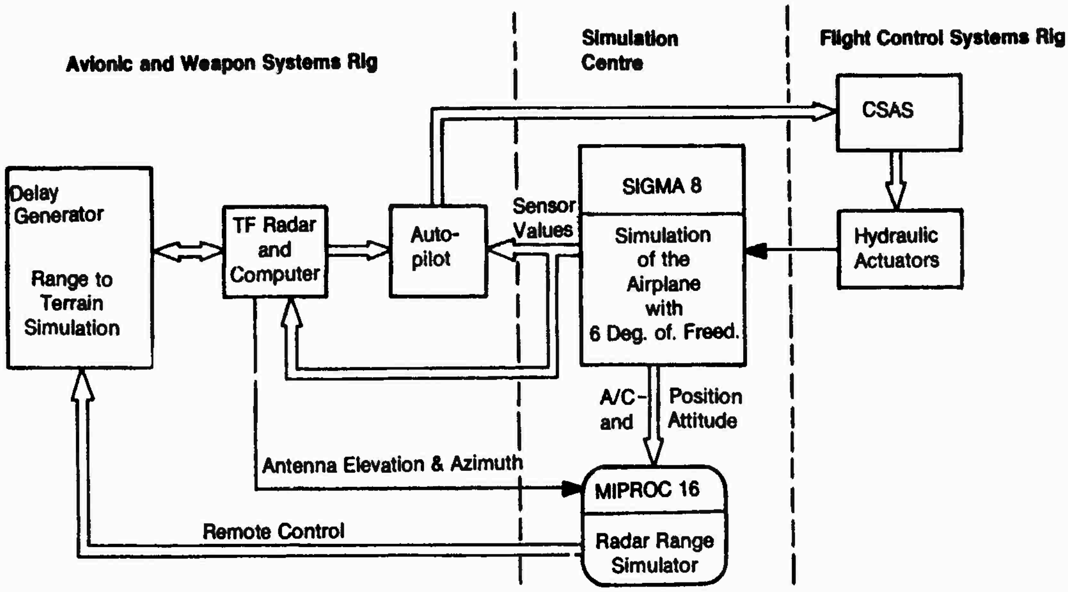

Figure 2: The Ground Operated TF System

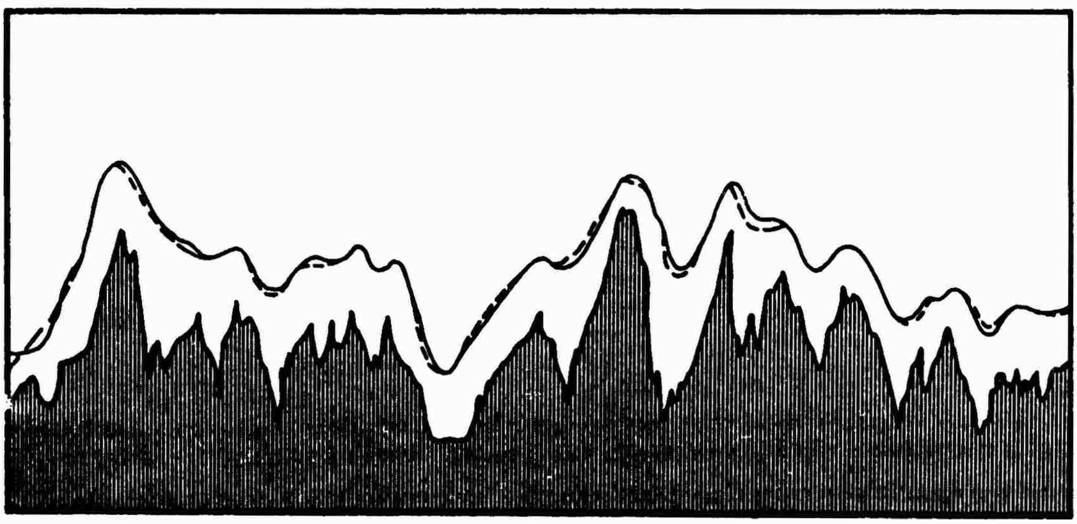

Figure 3: Comparison of Flight Test and Simulation Results

DISCUSSION

R.Cope, UK

You claimed that in IDAS the test definition is in plain English. Do you mean that literally or in a lexical sense only? Perhaps you could spend some words on the semantic and syntactical analysis?

Author's Reply

The communication between IDAS and the user is performed interactively via video terminals. The engineer specifies his test by answering successive questions generated by the system in direct readable English. In most cases he has to make a choice between actual possibilities presented in tables on display. On request additional "help"-information is available.

The system guided specification of a test is started at a common level and is particularized step by step. The compatibility of every input is checked with respect to the structure of the actual test as far as already known to the system.

By this way tests can be defined without a knowledge of a specific programming language like PASCAL, BASIC or ASSEMBLER. Since the dialogue is guided and limited by the system, an analysis of the free language is not necessary and of course not part of the system.

R.Cope, UK

The necessity to input such detailed information as channel numbers implies that the tester must have a detailed knowledge of the avionic system although you emphasized during your paper that the Avionics Data File contained all such detailed configuration data.

Author's Reply

The channel number mentioned is a pure key enabling an automatic access to information stored in the Avionic Data File. This key can be found easily in a short form directory on basis of device names like IN or ADC. A detailed knowledge of the avionic system is not required.

R.A.C.Smith, UK

When the rig is being operated in its fully integrated state, i.e. Flight Controls Avionic, etc. is it necessary to use actual Aircrew to fly the rig or is this task within the scope of the rig test engineers?

Author's Reply

The rig-"flights" are guided and controlled by test engineers with limited experience in flying airplanes. Only in very special cases are actual Tornado aircrews involved.

R.Davies, UK

How in rig evaluation of operational scenarios do you simulate the different levels of crew experience in the tri-national Tornado programme? In the specific case of the West German Marineflieger and the Italian Aeronautica Militare – neither had Air Navigator/Weapon System Operators suitably experienced as rear crew members prior to the Tornado acquisition, to fly with their F-104 experienced pilots. Their level of operational experience must therefore be lower than the Luftwaffe or RAF Tornado crews and this must affect the human factors aspect of rig work.

Author's Reply

The rig was mainly used for the initial avionic development and system integration. Up to now human factors were investigated in special cases only, e.g. concerning the effectiveness of warnings for terrain following flights.

If evaluation of operational scenarios are to be performed as a future task for the rig and the connectable simulations, the different levels of crew experiences must be taken into consideration.

HARDWARE-IN-THE-LOOP SIMULATION TECHNIQUES USED IN THE DEVELOPMENT OF THE SEA HARRIER AVIONIC SYSTEM

by

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UK

Abstract: Simulation using

The use of simulstion utilising airborne hardware in the loop during the development of avionic systems is now a well established technique used by airframe and weapon system contractors. However, each new weapon system produces a different set of problems that usually requires a change of technique in order to satisfy ~~the~~ test requirements for the system. This paper gives a brief overview of the Sea Harrier avionic system and describes the techniques used by British Aerospace in the development of this system. Descriptions of the special-to-type interfaces required to drive the forwsrd looking radar, navigation system, automatic flight control and HUD/weapon aiming computer are given, ~~are~~ along with some specific development problems that were overcome using the techniques described.

2. Introduction

The Sea Harrier V/STOL aircraft avionic system was oonfigured for single sest operation at sea to sssist the pilot in the detection, identification, sequisition snd delivery of a vsriety of weapons agsinst airborne or surface targets using new sensors and a combined computing/displsy system. The task of British Aerospsce, ss wespon system contractor, was to ensure this hardware and assooisted softwsre wss tested, validated and integrated into the aircraft in an efficient snd effective msnner. This wss schieved by BAe, in stages ss follows:

a) Mathematioal Modelling

A full mathemsticsl model of the aircraft and its wespon system wss developed on the simulator looated st the British Aerospsce - Hatfield Division. Use of representstive flight hsrdware was restricted to cockpit controls only - sll systems being emulsted or built using speoisl to type hsrdwsre. This modelling sotivity, being ahead of the main hardware/softwsre development, achieved the following:

- Good cockpit ergonomio design.
- Development of new air-to-sir wespon aiming and interception solutions.
- Development of hesd up snd hesd down display symbology.
- Development of landing guidsnce lsws and techniques.
- Development of loft and sir to ground bombing displays and solutions.

b) Ground Testing

Ground testing of the wespon system was conducted, as described in this paper, at the flight test sirfield at British Aerospace, Dunsfold, Surrey.

c) Flight Testing

Initial flight development of the weapon system was carried out using a two seater Hunter T MK 8M aircraft fitted with a full airborne instrumentation system. Final weapon system proving was then carried in the Sea Harrier.

3. Description of Sea Harrier FRS Mk 1 Avionic System

The Sea Harrier FRS Mk 1 (Fighter, Reconnaisance and Strike) aircraft programme was approved in mid 1975 and whilst 90% of the airframe, power plant and mechanical systems were common with the earlier Royal Air Force Harrier the avionics (designated the navigation/attack system) was about 90% new. Since the prime role of the Sea Harrier was as a fighter/interceptor the navigation/attack system was configured to satisfy this air-to-air requirement. However it had also to provide a good air-to-ground and air-to-sea surface weapon delivery capability whilst being able to operate autonomousl, at sea.

The essential features of the navigation/attack system are shown in Figure 1 and comprises the following sub-system:-

- o Head up display and weapon aiming computer (HUD/WAC).
- o Navigation, heading and attitude reference system (NAVHARS)
- o Radar
- o Doppler radar
- o Air data system (ADS)
- o Tacan
- o Compass system
- o Pilot's display recorder (PDR)

The following sub-systems are associated with the navigation/attack system but are regarded as peripheral equipment:-

- o UHF homing
- o Radar altimeter
- o IFF
- o Armament Control
- o Automatic flight control
- o Pilot Static system
- o Head down instruments
- o Fuel system indication
- o Radar warning receiver
- o Microwave aircraft digital guidance equipment (MADGE)

The radar, HUD/WAC and NAVHARS systems are interfaced via 64 KHz serial digital data links with the other sub-systems retaining their conventional analogue and discrete interfaces (Figure 1).

3.1 Head Up Display and Weapon Aiming Computer

The HUDWAC is the central processor and symbol generator system and is built by Smiths Industries Ltd. It comprises three units:

- o Pilots display unit
- o Weapon aiming computer/electronics unit
- o Control Panel

The operational flight software was supplied by Smiths Industries Ltd and written in the UK standard language - CORAL 66.

The salient features of the weapon aiming computer are summarised below:

o Notation	General purpose, 16 bit, fractional, fixed point, double precision, two's complement.
o Storage	32K read/write core plus 8K read only PROM.
o Instruction execution rate	475,000 operations/sec (depending upon instruction mix).
o No of instructions	59 microprogram controlled.
o Interrupts	Eight level vectored priority.

o I/O	Program controlled Direct Memory Access
o Serial I/O	3 serial data links in and 3 out.
o Discrete I/O	48 input discretes 14 output discretea
o Analogue I/O	Inputs : 48 d.c. 4 synchro 1 resolver Outputa: 8 d.c.
o Software	Coral 66 + assembler

The HUD/WAC provides the following facilities to the pilot:

1. Display of aircraft attitude and heading and vertical velocity.
2. Display of other flight information by pilot selection e.g. IAS, angle of attack and sideslip.
3. Display of navigation aids - UHF Homing and TACAN.
4. Output of flight information to radar diaplay in a video format.
5. Computation and display of all air-to-ground weapon aiming.
6. Solution of air-to-air weapon aiming equations.
7. Display of Sidewinder firing solution.
8. Pointing of radar antenna in aome weapon aiming modes.
9. Manual or automatic release of weapona.
10. An integral independent standby sight.

The operational modea available are shown in Table I and are selected by a combination of controla on the HUD/WAC control panel, missile control panel and armament control system.

TABLE 1

Mode	Deacription
V/STOL	Display of relevant flight information during vertical and short take off and landing phase.
Bearing	Uaed to establish aocurate heading datum for preflight inaertion into NAVHARS aystem.
Launoh	Uaed during ship ramp launch of aircraft.
General	General navigation mode.
Air-to-Air	Provides a comprehenaive set of gun and missile computationa, control and displaya dependent upon weapon aeleotion and radar statua.
Visident	Provides ateering information to enable targeta to be identified at close range at night or poor visibility.
Air-to-Ground	Manual releaae of guna, rocketa or bomba. Automatic release of bomba.
PIA	Pilot Interpretated Approach - providea guidance in azumith and elevation during landing phase using navigation, radar or landing aid data (MADGE).
REV	Reveraionary navigation and weapon aiming display.

3.2 Navigation, Heading and Attitude Reference System

The NAVHARS system provides navigational, heading and attitude information to the pilot, stabilisation of the forward looking radar antenna, ground stabilisation of a radar target marker and velocity information for weapon aiming computing. It comprises the following three units and is manufactured by Ferranti Ltd:

- o Platform navigational (PN)
- o Electronics unit, navigation (EUN)
- o Display navigational control (DNC)

The NAVHARS requires information from other systems in order to fulfil its functions and together with the following forms the overall navigation system:

- o Air data computer providing TAS and barometric height.
- o Doppler radar providing doppler velocity along and across heading and perpendicular to the aerial.
- o Forward looking radar providing radar target marker range and bearing, antenna elevation angle and radar hand controller outputs.
- o Tacan providing range and bearing to selected station.
- o Fuel system providing fuel contents and fuel flow rate.
- o Flux valve providing magnetic heading.

3.2.1 System Operation

The NAVHARS system was designed to operate autonomously at sea and does not require a data link from the ships navigation system to the aircraft. All data required for alignment can be inserted by the pilot and comprises ships speed and heading, present position and sea motion. The platform can be operated in a magnetic or memorised heading mode with selection of the mode being at the pilot's discretion. Alignments at sea are achieved using the memorised mode and can be accomplished along or offset from ships heading.

The NAVHARS operates in the following navigate modes:

a) Doppler damped - a doppler/inertial mix mode.

b) True air speed damped - an inertial damped with TAS mode.

c) Pure inertial - a Schuler tuned inertial loop mode.

d) Damped inertial - this mode is automatically entered following NAVHARS alignment but before doppler or TAS velocities are available.

The doppler velocity damped mode is the primary mode but under some conditions, particularly during manouevres, doppler velocities are not available. At these times the system switches automatically to an inertial mode of operation and if the doppler remains invalid for more than two minutes then, if TAS is available, the system will switch to a TAS damped mode with stored wind as a reference. If TAS is invalid the system will revert to a pure inertial mode. The system will revert to doppler damped any time doppler becomes valid.

Table II shows the facilities provided by the NAVHARS.

TABLE II

Facility	Function
1. Insertion and Display of Destinations	Storage and display of ten destinations in either Lat/Long or grid co-ordinates.
2. DNC Display	Display and computation of flight and navigation information.
3. Position updating (fixing)	Updating of position information in navigate mode as follows: a) On-top planned or unplanned fix. b) Tacan fix c) Radar display fix d) Radar locked target fix
4. Insertion of Destinations	Insertion, in flight, of future destinations without direct knowledge of their co-ordinates as follows: a) Present position insertion as a destination. b) Radar display insertion as a destination. c) Locked target insertion as a destination.
5. Change of grid origin	Change of grid origin, without direct knowledge of the Lat/Long co-ordinates of the new grid origin.
6. FROT	Computation of Fuel Remaining On Task.

3.3 Radar

The Blue Fox radar is a lightweight I-band search radar used for the detection and tracking of airborne and surface targets and for the interrogation of transponder equipped aircraft or surface vessels. The radar comprises nine line replaceable units (LRU's) five of which are located in the nose of the aircraft and four in the cockpit and is built by Ferranti Ltd.

The radar provides the following functions:

- A blind search about aircraft heading against airborne or surface targets using a normal head down display. Sector PPI or B Scan displays can be selected by the pilot.
- A facility to detect small airborne and surface targets.
- A means of tracking a selected target with range and bearing displayed.
- A means of tracking jamming targets.
- Tracking of targets acquired visually on the radar boresight.
- Detection of friendly targets by interrogation of their transponders.
- An interface with the navigation/attack system.

3.4 Automatic Flight Control System (AFCS)

The AFCS is an integrated autostabilisation (autostab) and autopilot flight control system, provided to assist the pilot in maintaining stability during jetborne and transitional flight and to control the flight path in wingborne flight without pilot assistance. The necessary pitch and roll demands on the control surfaces and/or reaction controls share auto control channels common to both autostab and autopilot. A separate yaw autocontrol channel is peculiar to autostab. The AFCS is built by Marconi Avionics Ltd.

3.4.1 Autostabiliser Facilities

- o Operates over speed range 0 - 250 knots.
- o Rate gyro control is provided in pitch and roll axes.
- o Yaw channel control is provided by lateral acceleration, yaw rate and lateral stick position.

3.4.2 Autopilot Facilities

- o Operates at speeds >250 knots.
- o Provides the following autopilot modes:

  a) Elevation and bank attitude hold.
  b) Heading hold
  c) Barometric height hold

4. Description of Sea Harrier Avionic Test Facility

The Sea Harrier avionic system facility comprises three test sections as follows:

1) Vendor test equipment - used for acceptance and specification compliance testing.

2) Integration rig - used for quasi-static integration checks with three test benches for radar, NAVHARS/doppler/compass system and HUDWAC. These portable benches are also capable of performing equipment serviceability checks and were also used to support development flight trials at sea on HMS Hermes and HMS Invincible.

3) Dynamic development rig (DDR) - used for:

   a) Total avionic system integration.

   b) To provide a dynamic test facility by driving the navigation/attack system via a VAX 11/780 and floating point system AD 120 array processor for hardware and HUDWAC software test and validation.

   c) Development of autopilot control laws.

4.1 Dynamic Development Rig

The prime purpose of the DDR is to drive avionic navigation/attack hardware in-the-loop during Sea Harrier attack profiles. The philosophy adopted in designing the DDR was to include, where feasible and cost effective, all weapon system components. It was however decided not to include the basic aircraft sensors such as attitude and rate gyros and pressure sensors which would involve the use of expensive and unwieldy high bandwidth rate tables or pneumatic equipment. The omitted sensor signals were generated by the simulator computer and injected, via dedicated interfaces, into the appropriate system, so as to minimise the hardware not included in the loop, as described in detail below. The DDR comprises four main sections.

Figure 2 shows the main signal flow for the DDR between the simulator interface and the navigation/attack system.

4.1.1 Hardware Rig Modules

Eight rig modules were built with the following functions:

Module	Function
1	Radar
2	HUDWAC
3	NAVHARS/doppler/compass system
4	Airborne Instrumentation
5	AFCS, ADC and radar altimeter
6	Armaments
7	Radio communication, TACAN, ESM
8	Missile systems

Each module with its equipment may be functioned independently of other modules either a) statically using analogue inputs from a static simulation panel and digital inputs via a data link word generator or b) dynamically using the VAX 11/780. In this way avionic equipments not available could be directly emulated.

4.1.2 The Simulator

This comprised an outside world display and a cockpit fitted with the following airborne avionic cockpit equipment.

- HUD and control panel
- DNC
- Radar display and controls
- Flying controls and AFCS control panel

4.1.3 The Central Computer

Figure (3) is a block diagram of the computer equipment in the Sea Harrier Dynamic development facility. It comprises a DEC VAX-11/780 computer system and standard peripheral equipment, operating system and language processors. A DEC PDP-11/10 computer is used to drive a monochrome cursive outside world display, and a very fast floating point array processor from Floating Point Systems Ltd is used to host the aircraft and equipment models. Additionally, a series of standard interface cards are used to drive the purpose built avionic equipment simulators. This facility is used for software development, data processing, compilation/assembly of airborne WAC programs and simulation activities. The equipment comprises:

- (1) DEC VAX-11/780 computer
  (2.5 Mbytes memory + floating point hardware)
- (2) 67 Mbyte disk drives
- (1) 256 Mbyte disk drives
- (2) magnetic tape drives
- (32) analogue-to-digital converter channels
- (12) digital-to-analogue converter channels
- (1) printer
- (2) printer/plotters (electrostatic)
- (1) flat-bed plotter
- (20) CRT/keyboard terminals
- (1) communications sub-system (networking)
- (1) FPS AP-120B floating point array processor
  (8K main data memory + 4K program source memory)
- (1) DEC PDP 11/10 computer (6K words memory)

The following software is currently in use in the facility:-

System Software

- o VAX/VMS V3.1 Operating system
- o MACRO-32 V3.0 Assembler
- o VAX-11 FORTRAN V3.1 Compiler
- o VAX-11 DATATRIEVE
- o VAX-11 COMMON DATA DICTIONARY
- o EDT Screen editor
- o FPS APEX array processor executive
- o TOAST (AP software development system)
- o Plotter support packages
- o Graphics terminal support package

Avionic Support Software

- o Sea Harrier small perturbation model
- o Sea Harrier low speed model (including full aerodynamics, hover dynamics and engine effects)
- o Avionic equipment models
- o Standard atmosphere model
- o Stores ballistics models
- o Target control system
- o Smith's Industries RA22 CORAL cross-compiler
- o Smith's Industries SICOL assebler/linker
- o General plotting package

4.1.4 Hardware Interfacing

In order to drive the navigation/attack system hardware in a dynamic mode special to type interfaces between the VAX-11/780 and the airborne equipment were developed. The primary interfaces are described as follows.

4.1.4.1 Radar Interfaces

The radar angles and range interfaces are shown in Figure 4A and 4B respectively. The VAX 11/780 emulates a target position which is differenced with the antenna position from the radar. The difference is the position error which is compared with the beam width and if within activates a gate latch which allows the radar to lock onto the target. The position errors are sent to the radar which allows the antenna to be driven to the simulated target position. Range is generated via VAX 11/780 control of the timer shown in Figure 4B. Radome aberration effects are emulated by adding the appropriate aberration angle to the target position.

4.1.4.2 NAVHARS Interface

The NAVHARS velocity interface is shown in Figure 5A. The VAX 11/780 generates a demanded velocity which is differenced with the actual velocity from the EUN. The error velocity is converted from a digital to analogue signal, multiplied by gain K and converted to a demanded acceleration. The gain K is set such that the digital loop is deadbeat i.e. the velocity error is driven to zero in one loop sample period. This is differenced with a torqueing current equivalent to the actual acceleration. The resultant signal is then passed through a low pass filter and modulated to become the acceleration error fed to the EUN. Velocities are generated by integration within the EUN. Three identical circuits are used for Vx, Vy and Vz. The synchro angles are generated via digital/synchro converters as shown in Figure 5B.

4.1.4.3 Doppler Interface

The doppler interface is shown in Figure 6. the VAX 11/780 generates demanded doppler velocities to a variable frequency sine wave oscillator. This oscillator produces the doppler frequencies appropriate to the demanded velocities and are fed to the spectrum generator which adds to each doppler frequency a noise spectrum. This spectrum has a frequency bandwidth that is automatically adjusted for speed variation. The final simulated doppler velocity signals are then fed to the IF stage of the doppler.

4.1.4.4 HUDWAC Interface

The HUDWAC and ADC interfaces are shown together in Figure 7 since these two units were generally operated together during HUDWAC software testing and validation. This ensured that ADC lags (with the exception of the pilot static system lags) were always present by virtue of using the flight hardware. The ADC interfaces are straight voltage representation of pitot and pitot-static pressures driving servo controller force balance units. The NAVHARS and radar serial data links were generally provided by flight hardware driven by the VAX 11/780 as described above. However these data links could be provided via equipment emulations within the VAX 11/780 and a parallel to serial interface. This proved to be an extremely useful rig facility particularly during development of air-to-air interception course computing and missile launch success zone software.

5. Dynamic Test Facility - Test Experience and Limitations

5.1 The dynamic development facility has proved useful for both early evaluation of weapon system problem areas and new system development and has significantly reduced the total flying hours required on the development programme. Two specific development areas that illustrate the flexibility and uses of the facility are described briefly below:

5.2 Autopilot Height Hold Limit Cycle

During initial autopilot flying intermittent limit cycling of an unpredicted nature occured in height hold. The frequency of the oscillations was higher than anticipated, resulting in unacceptable peak 'g' levels as seen by the pilot, and was worse at altitude. This type of limit cycling had not been seen during the hardware-in-the-loop simulation that had been carried out before flight and it was suspected that the cause was an intermitent non-linearity which was more complex than the anticipated Air Data Computer (ADC) dead-space. This suspicion was confirmed by running the simulation as shown in Figure 8 with several different ADC's and by operating the system at different engage heights where the limit cycle observed in flight again occured intermittantly.

5.2.1 Flight Results

A typical limit cycle is shown in Figure 9. The limit cycle has a period of some 10 seconds and an amplitude in height of approximately 20 feet, the resulting normal acceleration has a peak amplitude of approximately 0.2g. The period and amplitude of the limit cycles were found to vary with height and with the particular ADC fitted. A period of approximately 10 seconds was, however, typical of the altitude.

5.2.2 Simulation

The height limit cycle was reproduced on the Dunsfold DDR with the hardware ADC and autopilot in the loop. Although the limit cycling is less smooth, due to lack of aircraft vibration the simulator and flight results compare very well with respect to limit cycle frequency (See Figure 9).

Simulator studies indicated that a modification to the height control law to incorporation a complementary mix of baro height and height rate would prove effective in curing the height limit cycle.

An autopilot was modified to include the proposed solution and was flight tested. During the first, and subsequent flight tests no limit cycling in height hold was observed and the modification was incoporated, without further change, in production autopilots.

5.3 Advance Radar Tracking System

Development work is at present being carried out on an advanced radar tracking system for the Sea Harrier. The proposed system should have benefits in terms of much improved estimates of a targets velocity and acceleration and an enhanced ECM capability. A sophisticated system of this type would normally require many flight hours to optimise the system equations. It is however, hoped to minimise this time by means of employing the following two simulation methods:-

(a) VAX 11/780 Control of the Blue Fox Radar

The Dynamic Development Rig (DDR) is being modified to allow direct VAX 11/780 control of the radar, the VAX being programmed to simulate the weapon aiming computer processing and radar control functions. The proposed VAX/Radar simulation is shown in Figure 10A. A simulation of this type is attractive for several reasons:-

(i) Simulation results involving a hardware radar will be available in advance of, and may affect the contents of, the HUDWAC software package.

(ii) The tracker equations will be programmed in a high level language in a 'user friendly' environment i.e. the system modification would prove far simpler than the production of a revised HUDWAC program.

(iii) The use of real targets, either 'targets of opportunity' or aircraft briefed to perform certain manoeuvres within the DDR radar field of view, would allow assessment of the effect of genuine radar noise on the system.

(iv) It is intended at a future date to enhance the target simulation to include ECM effects.

(b) Full Hardware-in-the-loop Simulation

The second phase of the system development would involve a fully integrated weapon system as shown in Figure 10B and would comprise:

(a) Simulation with real targets with the NAVHARS EU and PN in the loop, i.e. no 'aircraft' manoeuvres.

(b) Simulation with synthetic targets and with the NAVHARS PN simulated by the VAX 11/780.

The simulation involving real targets will require a minor modification to the HUDWAC software, such that the corrections for radome aberration are zeroed, as the DDR radar operates without a radome. Aircraft ground tests against a manoeuvring target would complete the pre-flight testing and, when compared to the rig results, would indicate any problems specific to the aberration correction software.

This simulation will enable the problems associated with delayed sensor data, implicit in a digital data stream weapon system of this type, to be fully investigated before flight.

6. CONCLUSIONS

The test procedures and test rig configuration using flight hardware in the loop adopted by British Aerospace significantly reduced the total flying hours required during the Sea Harrier development programme. The flexibility built into the test system has enabled BAe to respond quickly to problems and changes of requirement and has allowed advanced techniques to be studies and tested without major rig configuration changes.

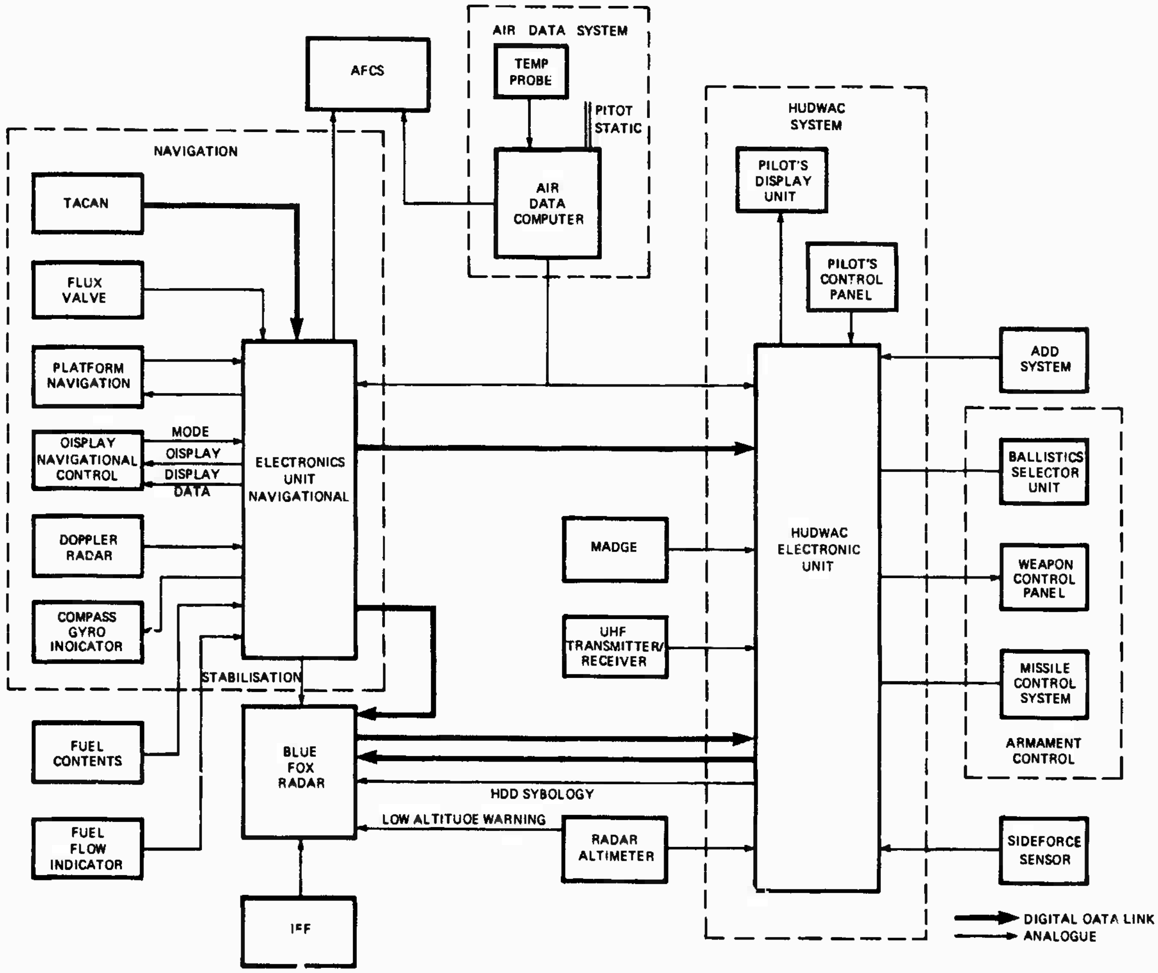

FIGURE 1. BLOCK DIAGRAM OF SEA HARRIER NAVIGATION/ATTACK SYSTEM

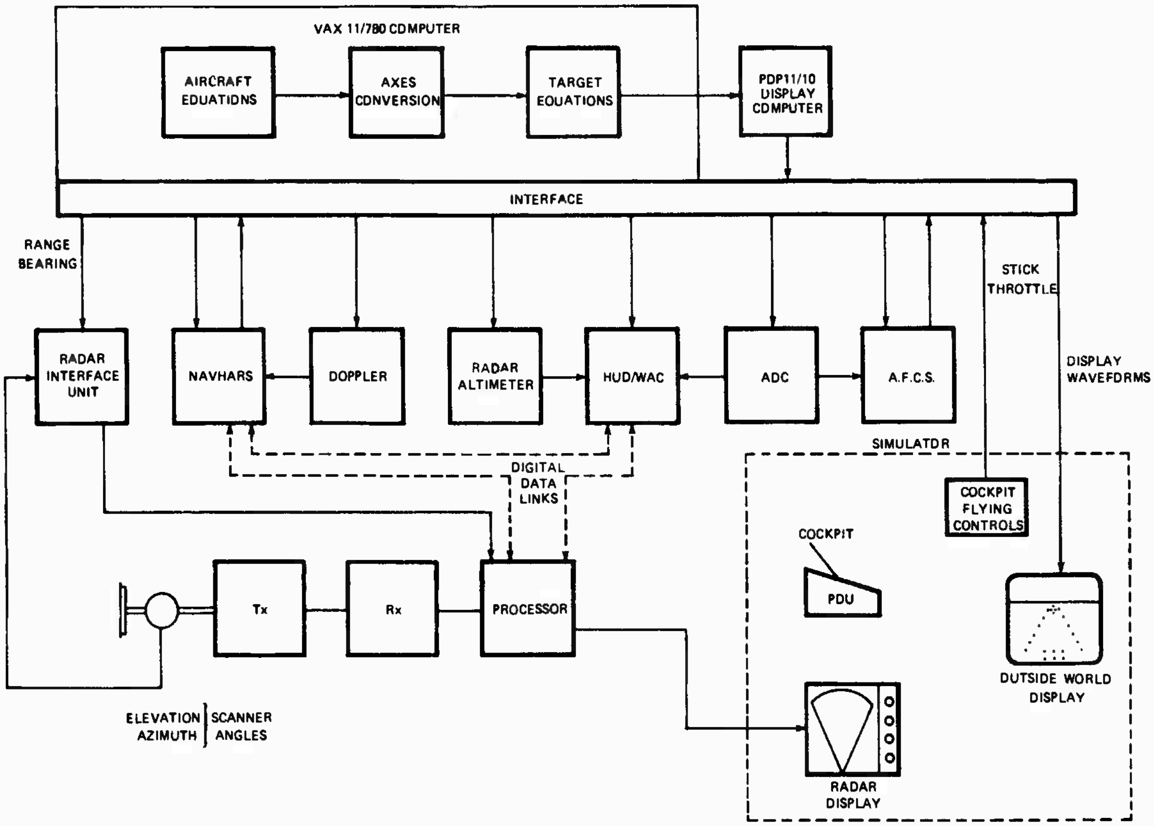

FIGURE 2. MAIN SIGNAL FLOW BETWEEN SIMULATOR INTERFACE AND NAV/ATTACK SYSTEM

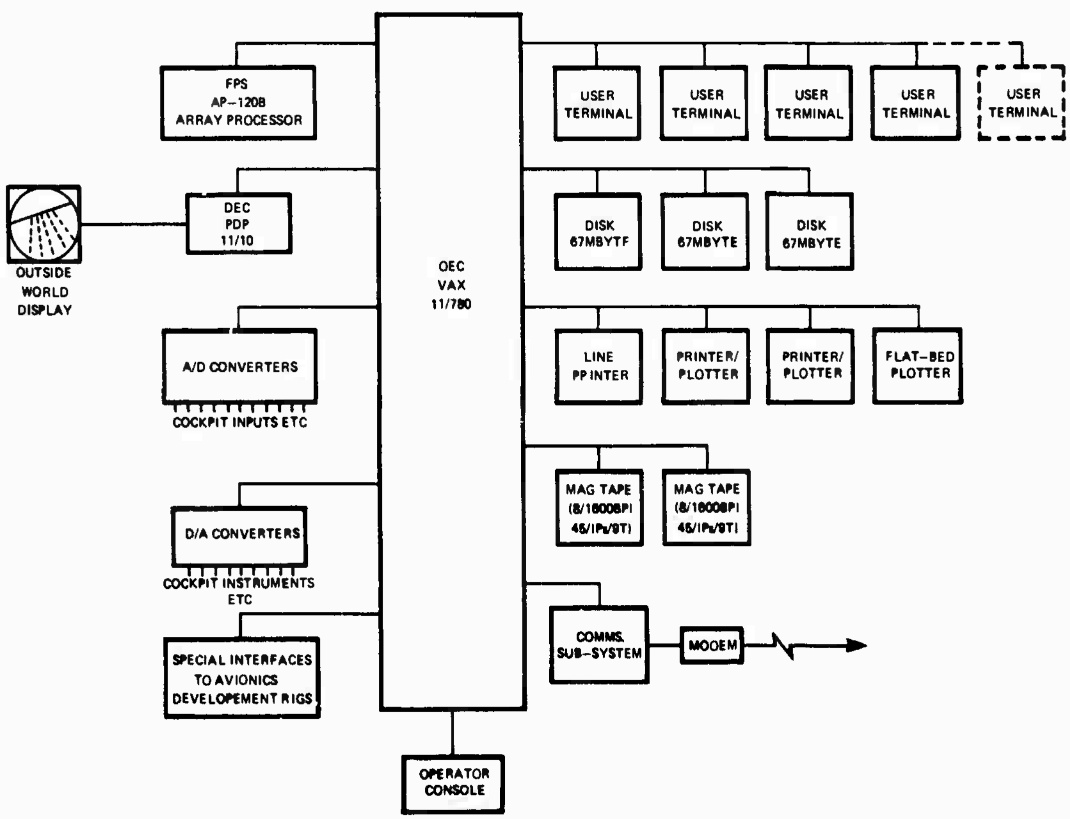

FIGURE 3. BLOCK DIAGRAM OF THE SEA HARRIER COMPUTER FACILITY

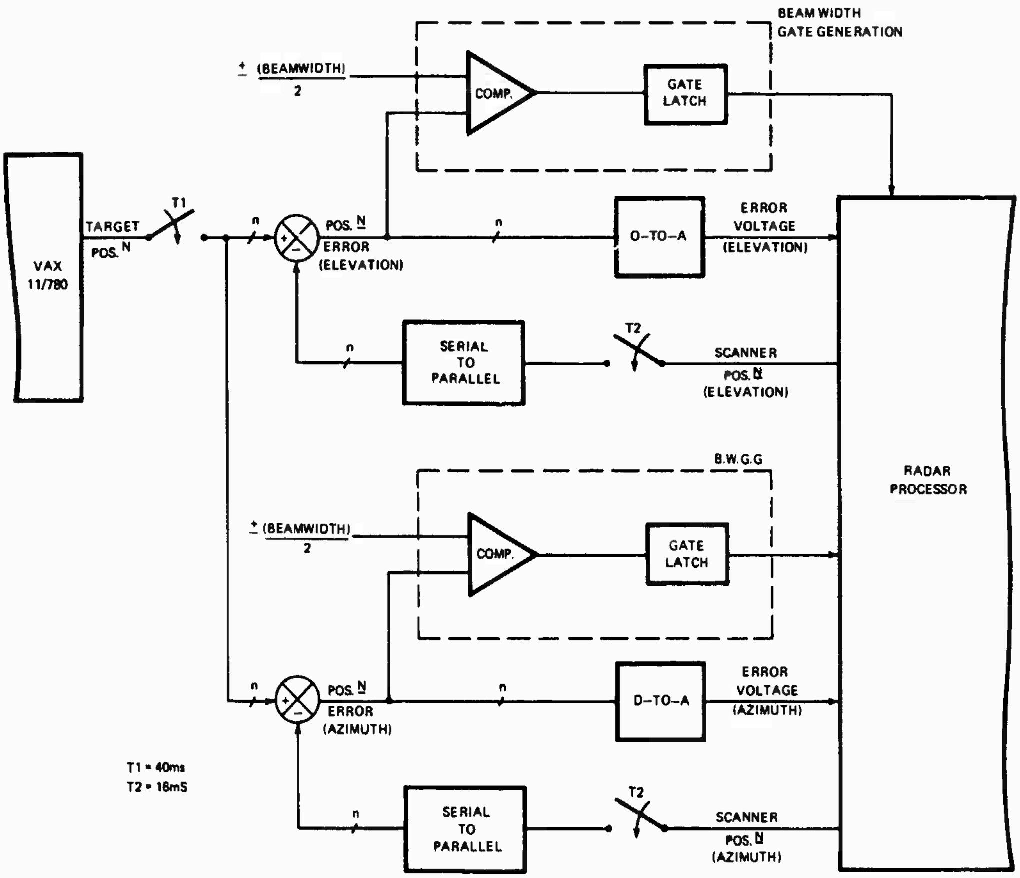

FIGURE 4A. VAX 11/780 TO RADAR INTERFACE – AZIMUTH AND ELEVATION ANGLES

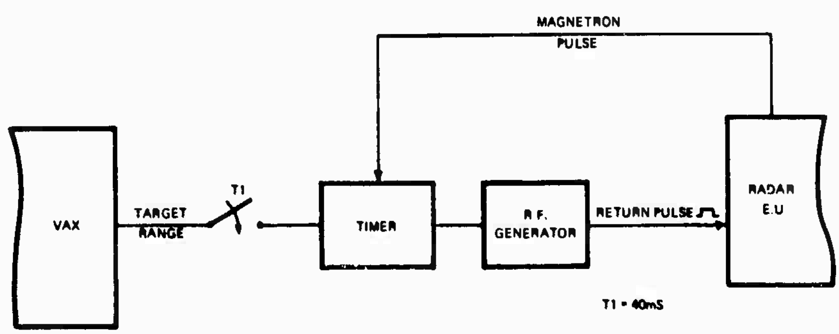

FIGURE 4B. VAX 11/780 TO RADAR INTERFACE – RANGE

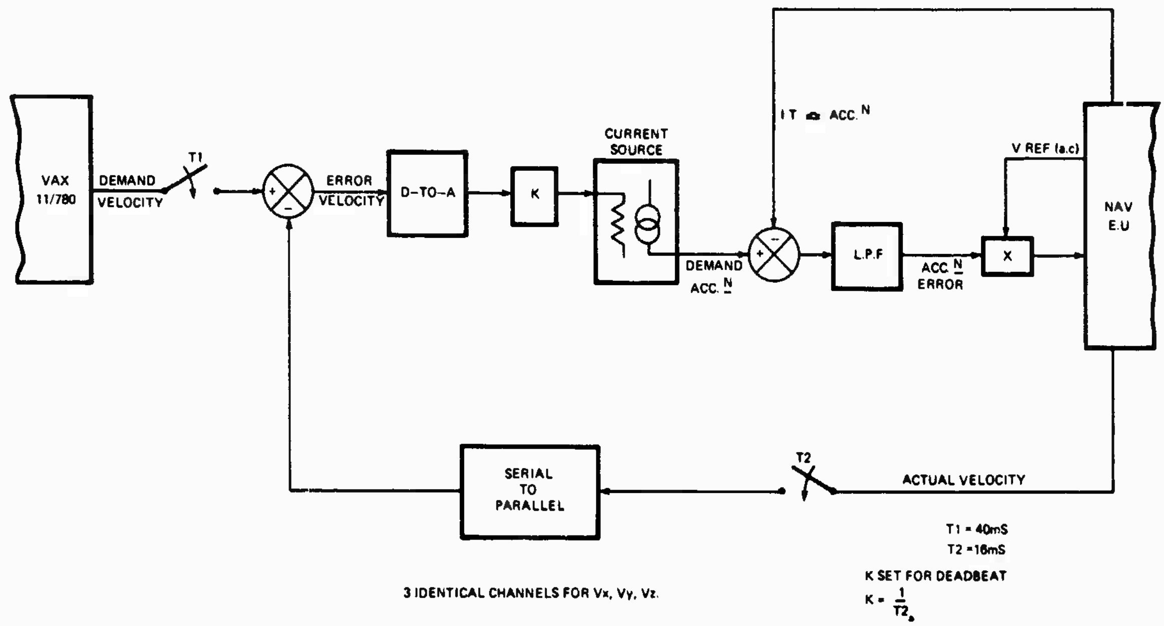

FIGURE 5A. VAX 11/780 TO NAVHARS – VELOCITY INTERFACE

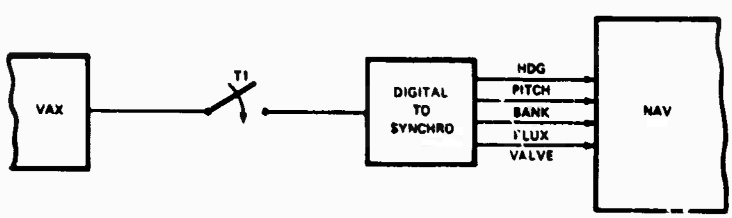

FIGURE 5B. VAX 11/780 TO NAVHARS INTERFACE – SYNCHRO ANGLES

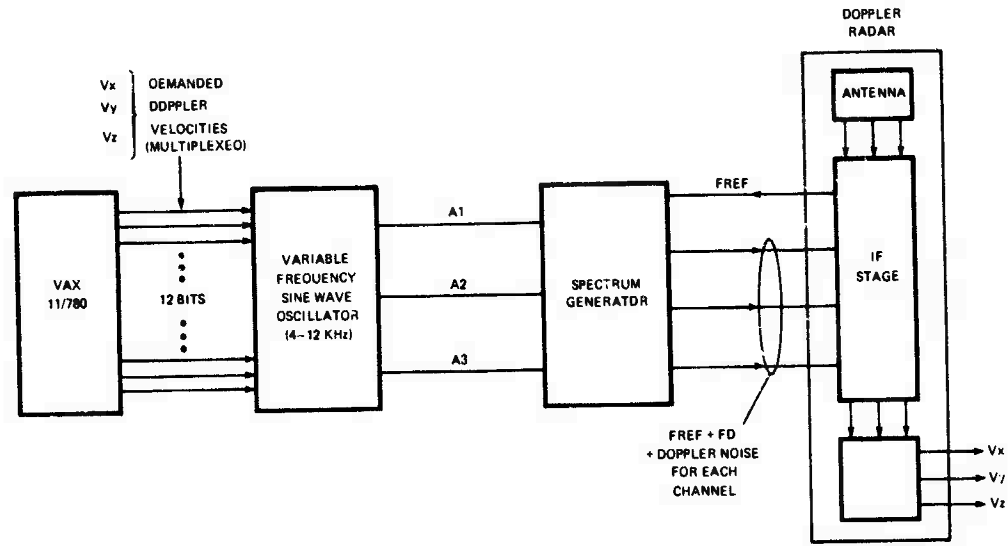

FIGURE 6. VAX 11/780 TO DOPPLER RADAR INTERFACE

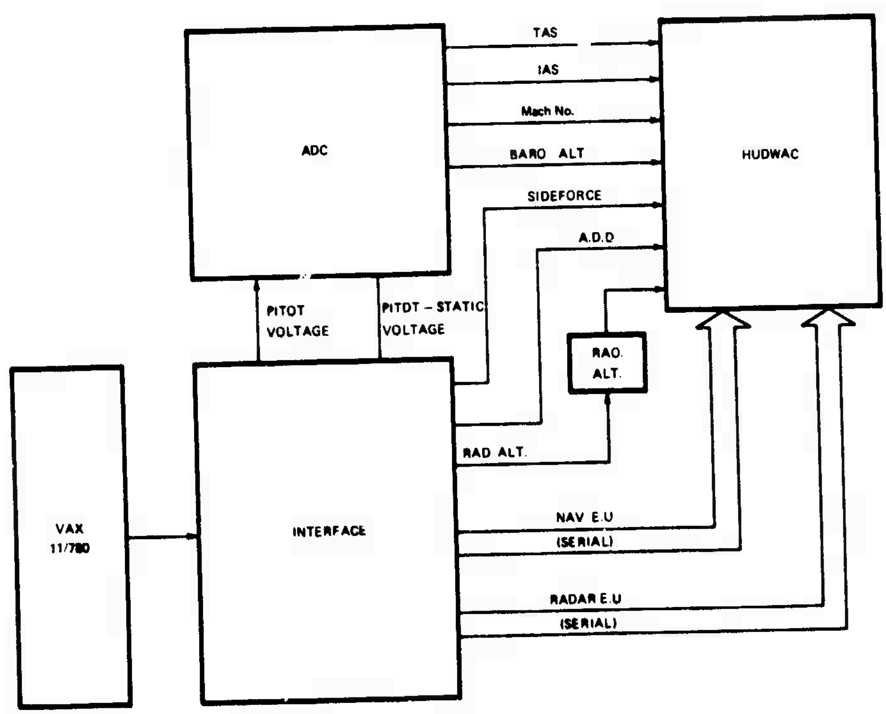

FIGURE 7. VAX 11/780 TO ADC AND HUDWAC – INTERFACES

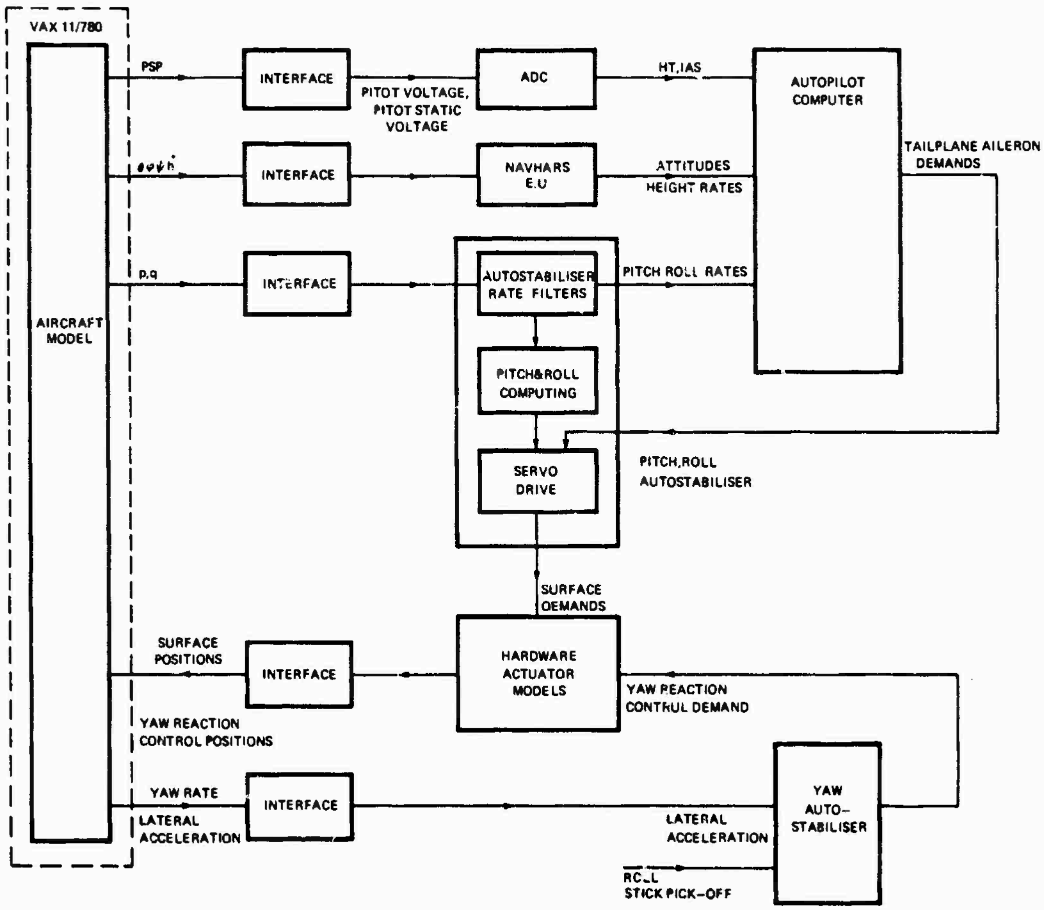

FIGURE 8. BLOCK DIAGRAM OF A.F.C.S. TO VAX 11/780 INTERFACE ARRANGEMENT

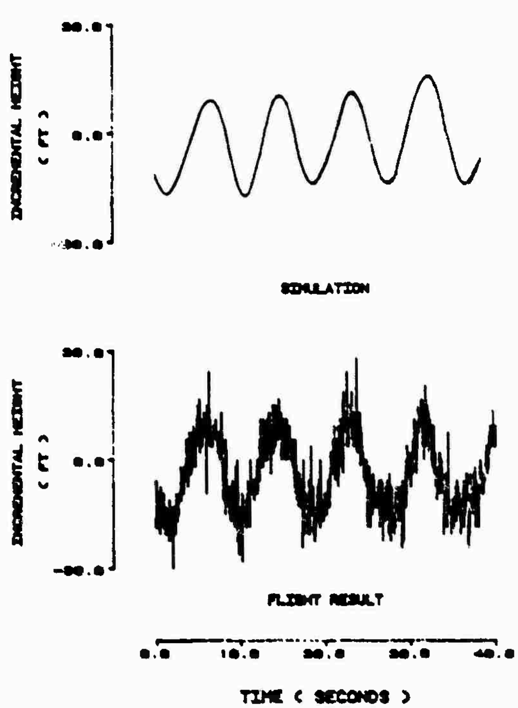

FIGURE 9: SEA HARRIER AUTOPILOT – HEIGHT LIMIT CYCLE

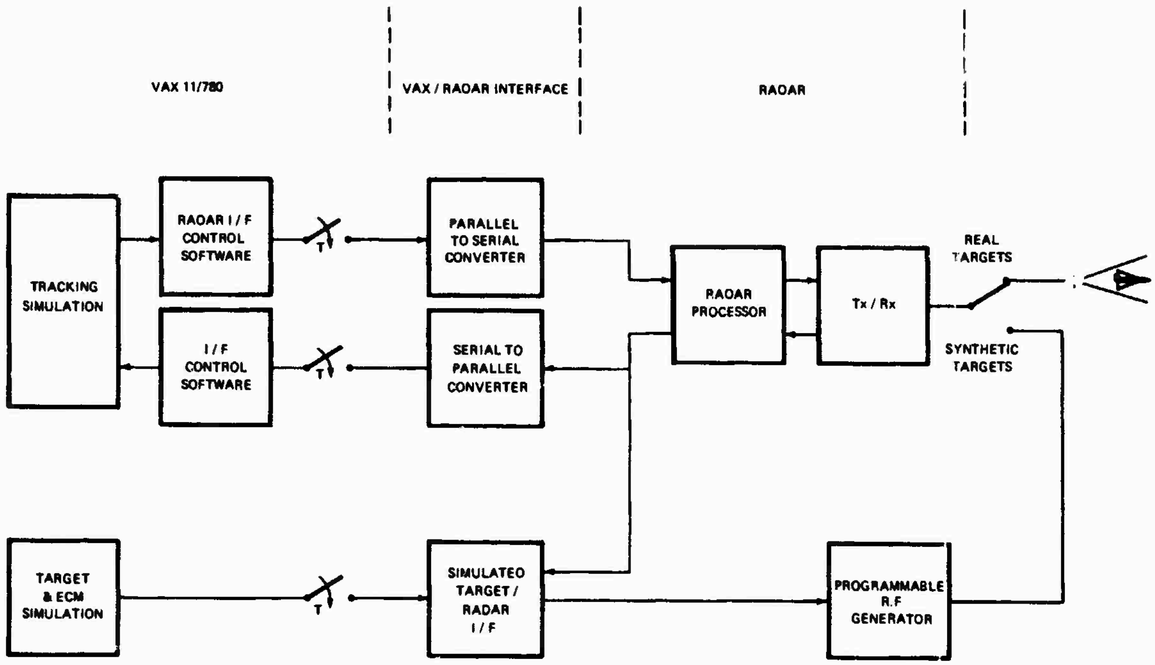

FIGURE 10A. VAX 11/780 TO RADAR TRACKING SIMULATION

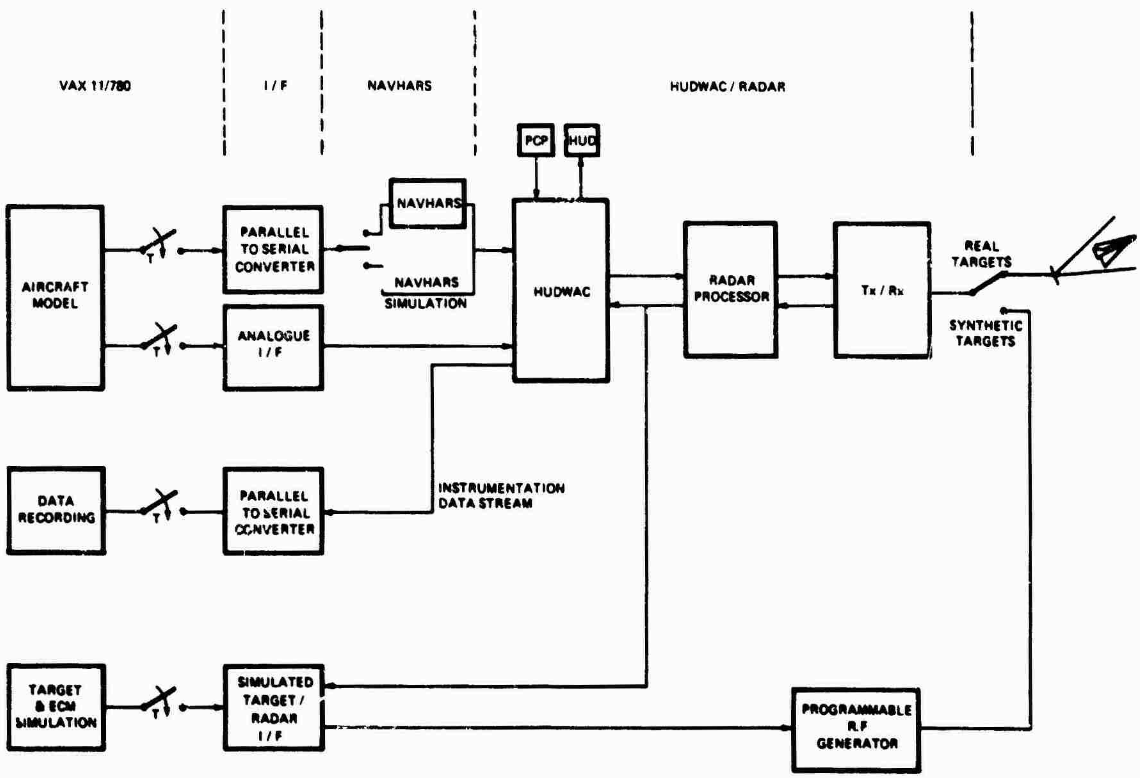

FIGURE 10B. VAX 11/780 TO HUDWAC AND RADAR SIMULATION

SIMULATION REQUIREMENTS TO SUPPORT THE DEVELOPMENT OF A FAULT TOLERANT AVIONIC SYSTEM

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ABSTRACT

With the need for advanced avionics system executives, several tools are essential in aiding the avionics system software engineer with the design and development of these executives. These tools should provide the user with an interactive simulation for the development of fault tolerant avionic systems and executives.

This paper presents the Northrop Avionics simulation package which ~~has been~~ was designed to support the development of fault tolerant avionic systems. Described is the Executive Support System, ESS, package which is presently being used as a development, test and verification tool for F-5G and F-18L avionics models. ESS provides an avionics system designer with a mechanism for developing and testing several avionic core configurations as well as for developing avionic simulation and application modules.

ESS consists of an interactive user interface that allows the user to configure the core avionics system as desired. Once the core system has been specified the user is able to specify whether centralized or distributed philosophies are to be used in the system executive. The executive consists of a user definable scheduler, system monitor and system support library. Application and system support software can be developed by the user and exercised by the ESS. In this way the ESS can be easily tailored to various applications and configurations. Since the development phase of any system includes debugging, ESS also provides the user with interactive symbolic debugging capabilities. These capabilities allow the user to examine, modify and monitor all of the simulation variables.

ESS is presently being enhanced to support the development of multiple scheduling processing elements, this will allow one program to stimulate multiple airframes or multiple processing elements in multiple user specifiable configurations.

MODERN AVIONICS SYSTEM REQUIREMENTS

- FAULT TOLERANT
  - CENTRALIZED OR DISTRIBUTED CONTROL
  - REDUNDANT RESOURCES
- INCREASED THROUGHPUT/DISTRIBUTED PROCESSING

MODERN AVIONICS SYSTEM SIMULATION REQUIREMENTS

- MODEL
  - CENTRALIZED CONTROL
  - DISTRIBUTED CONTROL
  - REDUNDANT RESOURCES
  - COMMUNICATION SCHEMES
- EVALUATE
  - THROUGHPUT
  - AVAILABILITY
  - RELIABILITY
- ALLOW FOR
  - SYSTEM DESIGN
  - SYSTEM ANALYSIS
  - SYSTEM IMPLEMENTATION
    - OFP DEVELOPMENT
    - SYSTEM INTEGRATION
    - SYSTEM TESTING AND VERIFICATION

MAJOR FACILITY SEGMENTS

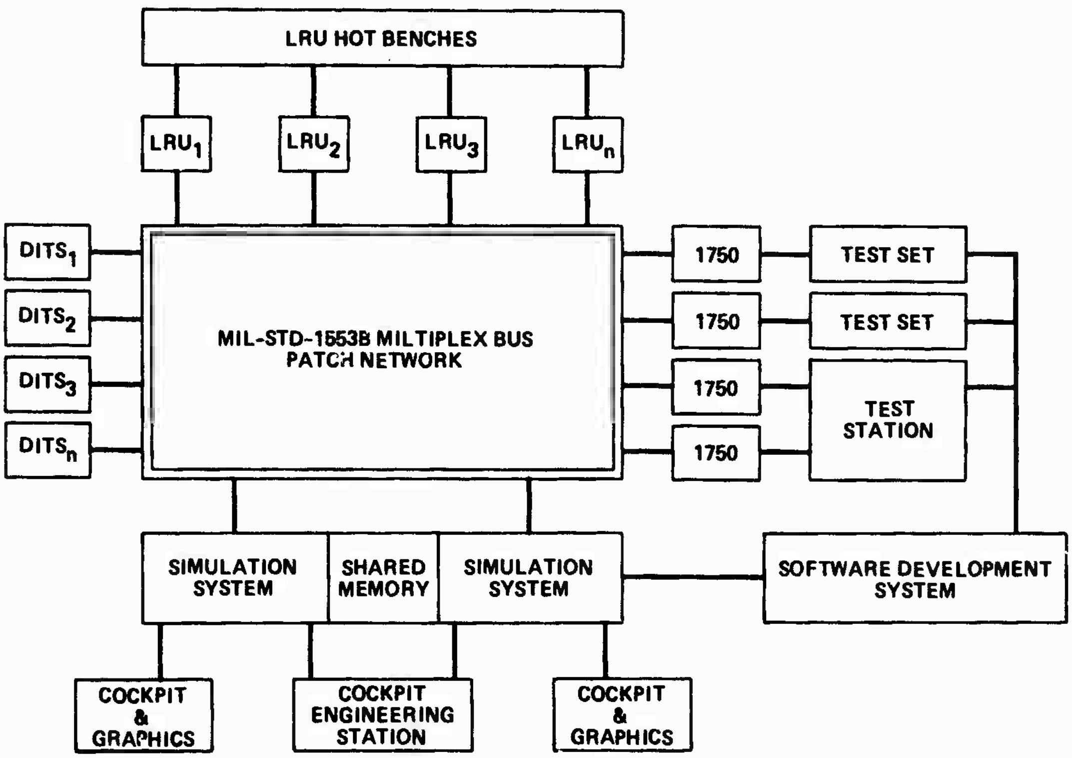
SIMULATION SYSTEMS

SOFTWARE DEVELOPMENT SYSTEM

LRU HOT BENCHES

DIGITAL INTERFACE TEST SETS

EXECUTIVE SUPPORT SYSTEM
HARDWARE CONFIGURATION



SIMULATION SYSTEMS

SIMULATION DEVELOPMENT PACKAGE (SIMPAC)

- GENERAL PURPOSE SIMULATION SUPPORT PACKAGE
- AID USER IN THE
  - DEVELOPMENT OF SIMULATION OR SUPPORT MODULES
  - DEBUGGING OF SIMULATION OR SUPPORT MODULES
  - DESIGNING AND CONFIGURING AVIONICS SYSTEMS
  - DEVELOPMENT AND DEBUGGING OF HARDWARE AND SYSTEM TEST SOFTWARE

SIMULATION SYSTEMS

SIMPAC CONSISTS OF

- RELINK
- SCENARIO
- BUSMON
- VIEW

SIMPAC

RELINK

- BASIC SIMULATION CONFIGURATOR
- THE USER HAS THE FOLLOWING CONFIGURATION OPTIONS:
  - SHAREABLE IMAGES/SEGMENTS
  - SHARED MEMORY
  - COCKPIT SUPPORT
  - GRAPHICS SUPPORT
  - BASELINED GENERIC MODEL SUPPORT
  - BASELINED F-20 MODEL SUPPORT
  - BASELINED F-18 MODEL SUPPORT
  - CUSTOM USER PROVIDED SOFTWARE

SIMPAC

SCENARIO

- SCENARIO IS THE INTERACTIVE USER INTERFACE PORTION OF THE NORTHROP SIMULATION PACKAGE
- SCENARIO WILL ALLOW A USER TO:
  - SET AND EXAMINE ANY LOCAL OR GLOBAL SIMULATION VARIABLE
  - SCHEDULE APPLICATION OR AVIONICS TASKS
  - LOG SIMULATION LOCAL OR GLOBAL DATA IN REAL TIME
  - MONITOR INTERACTIVELY SIMULATION DATA
  - RUN TIME CRITICAL FUNCTIONS IN REAL-TIME
  - INVOKE AN INTERACTIVE SYMBOLIC DEBUGGER

SIMPAC

VIEW

VIEW IS AN INTERACTIVE PROGRAM THAT WILL ALLOW A USER TO REDUCE DATA FILES THAT HAVE BEEN GENERATED BY:

- SCENARIO: SIMULATION INTERNAL DATA
- BUSMON: MIL-STD 1553B BUS DATA
- 1750 SUPPORT HARDWARE: INTERNAL RECORDED DATA

SIMPAC

VIEW

VIEW WILL ALLOW THE USER TO DISPLAY THE DESIRED DATA IN VARIOUS USER DEFINABLE FORMATS ON VARIOUS OUTPUT DEVICES

- THE USER MAY:
  - PLOT ONE VARIABLE AGAINST ANOTHER
  - OVERLAY MULTIPLE PLOTS
  - LIST DATA IN A TABULAR FORM
  - GET GRAPHICAL REPRESENTATIONS OF 1553B BUS UTILIZATION
  - DUMP SELECTED 1553B DATA IN HEX FORM OR ENGINEERING UNITS

SOFTWARE DEVELOPMENT SYSTEM

- INTERFACED TO SEVERAL 1750 TEST SETS AND STATIONS
  - ALLOWS DOWN LOADING
  - CENTRAL CONTROL OF INDIVIDUAL 1750 TEST STATIONS
    - REMOTE DEBUGGING
    - REMOTE EXECUTION

SOFTWARE DEVELOPMENT SYSTEM

THE SOFTWARE DEVELOPMENT SYSTEM CONSISTS OF SEVERAL 1750 AND JOVIAL DEVELOPMENT AND SUPPORT TOOLS:

- 1750 ASSEMBLER
- 1750 LINKER
- 1750 COMPUTER SIMULATOR
- 1750 SYMBOLIC DEBUGGER
- 1750 FORMATTER
- (FUTURE SUPPORT OF NEBULA)
- JOVIAL COMPILER
  - VAX AND 1750 TARGETED
- JOVIAL SYMBOLIC DEBUGGER
- (FUTURE SUPPORT OF ADA)

1750 COMPUTER SIMULATOR

THE ICS IS A GENERAL PURPOSE 1750A INTERPRETIVE COMPUTER SIMULATION THAT GIVES THE USER THE FOLLOWING CAPABILITIES:

- DEFINE BASIC CONFIGURATION OF THE SIMULATED 1750A
- LOAD THE LOAD MODULES INTO THE ICS
- SAVE THE STATE OF THE ICS
- EXAMINE/SET ALL 1750A REGISTER MEMORY LOCATIONS AND TRAP LOCATIONS
- SET AND REMOVE BREAK POINTS
- GENERAL CONTROL OF PROGRAM EXECUTION
- DISASSEMBLY OF 1750A CODE

1750 FORMATTER

- CREATES VENDOR SPECIFIC LOAD MODULES FROM THE OUTPUT LOAD MODULES FROM THE 1750 LINKER
- THE LOAD MODULE IS THEN EASILY TRANSFERABLE TO THE TEST STATIONS

1750 TEST SETS AND STATIONS

- STATIONS CONTAIN:
  - 1750 ASSEMBLERS
  - 1750 LINKERS
  - SYMBOLIC DEBUGGERS
  - APPROPRIATE 1750 INTERFACE HARDWARE

LRU HOT BENCHES

- PROVIDE LRU POWER
- PROVIDE PROPER ELECTRICAL STIMULATIONS
- INTERFACE TO THE SIMULATION OF SOFTWARE DEVELOPMENT SYSTEMS

DIGITAL INTERFACE TEST SET (DITS)

- GENERAL PURPOSE MINI/MICRO COMPUTER
  - EMULATE MIL-STD-1553B
    - LRUs
    - BUS CONTROLLER
    - BUS MONITOR
  - PORTABLE PIECE OF TEST EQUIPMENT
  - CAN BE USED AS AN INTEGRAL PROCESSOR IN AN AVIONICS CONFIGURATION

SUMMARY

FACILITY CAN BE USED TO:

- DESIGN AND DEVELOP AVIONICS SYSTEMS
- HARDWARE AND SOFTWARE TEST
- SUBSYSTEM AND SYSTEM INTEGRATION
- REDUCE DEVELOPMENT COSTS

DISCUSSION

W.Vogl, Ge

What is the effort required to introduce changes to the simulated scenario in the understanding that the scenario is one of the key elements in the simulator tasks?

Author's Reply

Changes to the scenario can easily be made during the runtime portion of the simulation by simply pausing the simulation, altering the desired parameters and then continuing the simulation. If halting the simulation is undesirable the user makes the changes via a second copy of the simulation that has been built with shared Images.

SOFTWARE TESTING OF SAFETY CRITICAL SYSTEMS

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SUMMARY

Safety critical systems must be thoroughly tested. Powerful test facilities and test concepts are very important. ~~The~~ This paper outlines ~~the~~ methods used for testing the software of the Tornado Autopilot and Flight Director System (AFDS). An overview of existing test systems is given, followed by a detailed presentation of a new test facility ~~i.e.~~ the AFDS Cross Software Test System (AFDS-CSTS).

The CSTS is an automated test tool. The AFDS is stimulated by a test computer with well-defined test data, generated via a test language. A software model running on this test computer is stimulated with the same test data. This software model is programmed according to the dual programming method based on the AFDS software specification. The test computer compares, cycle by cycle, the outputs of the AFDS with the software model outputs. All deviations from expected results are recorded for subsequent analysis.

The experience gained by installing and using this tool is reported. The quality and the test effectiveness of this test method are discussed. An important point is the cost of testing future software modifications.

1. INTRODUCTION

The role of digital computers for system control and the operation of modern weapon systems is expanding. Such computer applications are often safety involved, partially highly safety critical. So it is very important to achieve a high degree of reliability in the hardware and software.

This paper describes the software test methods applied to the Autopilot and Flight Director System (AFDS) of the Tornado. Especially a new automated test tool is presented: The AFDS Cross Software Test System (AFDS CSTS).

2. DESCIPTION OF THE SYSTEM TO BE TESTED

2.1 Global function

The Tornado AFDS is a digital integrated subsystem that allows the automatic control of the aircraft in all three flight axes. It also provides the pilot with informations on instruments and displays. So the pilot can manually guide the aircraft using the flight director mode or can monitor the automatic flight. The automatic modes include:
- Attitude/Heading hold mode
- Barometric altitude hold mode
- Mach hold mode
- Terrain following mode
- Radar height hold mode
- Bank angle hold mode
- Heading acquisition mode
- Track acquisition mode
- Autothrottle mode

The system (see Fig.1) receives its inputs from sensors, other subsystems and pilot inputs on the control stick or on the control panel. The autopilot receives inputs from:
- Inertial navigation system (INS)
- Secondary attitude and heading reference system (SAHRS)
- Air data computer (ADC)
- Main computer (MC)
- Radar altimeter (RA)
- Terrain following computer (TFC)
- Command and stability augmentation system (CSAS)
- Approach aids
- Throttle lever
- ' lot's control unit
- Pilot's control stick

The outputs of the AFDS are transmitted to the:

- Command and stability augmentation system (CSAS)
- Head up display (HUD)
- Attitude and direction indicator (ADI)
- Autothrottle actuator
- Pilot's control unit, engage indicator, central warning panel, maintanence panel.

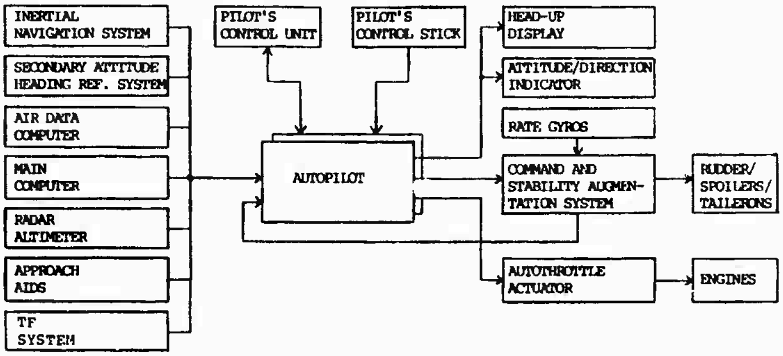

Fig.1.: Block schematic of Tornado Flight Control System

The AFDS outputs 'pitch rate demand' and 'roll rate demand' are transmitted to the CSAS and indirectly control the rudder, spoilers and tailerons of the Tornado. Especially in low altitude flight faults on these output signals could be very critical. Therefore the AFDS must be considered as a very safety critical system and all possible measures have to be taken to avoid hardware and software failures.

2.2 Protection against AFDS hardware failures

The AFDS is a duplex redundant system. Two almost identical computers, which are self-monitored execute an identical program. They only differ in some interfaces. The command signals at various stages of the computation are crossfed between the two computers and checked. If the signal difference exceeds a certain tolerance treshold, a hardware failure in one computer is assumed, a pull up is generated and the automatic mode is switched off. By this method the AFDS recognizes hardware failures and protects the system from their dangerous effects.

Software errors however would appear in both computers and would have the same effects in both computers. Software errors can not be detected by hardware redundancy. Therefore other measures have to be taken to avoid software errors and to validate the software.

3. MEASURES TO ACHIEVE HIGHLY RELIABLE SOFTWARE

3.1 Characterisation of the AFDS software

The AFDS software is a program of medium size. The number of instructions is less than ten thousand. It has been programmed in assembler language and loaded into PROMs. It is structured essentially into three main parts:

- The Mode and Failure Logic selects the operating modes according to the pilot requests, priority matrices and sensor validity. It determines the system reaction in the case of hardware failures. It consists essentially of logical AND- and OR-connections and delays of logical states.
- The Control Laws compute the commands in the three flight axes in dependancy of the selected modes and the sensor and pilot inputs. The main part are arithmetic computations, filters, limiters, integrators.
- Built-in test equipment (BITE) routines

The Mode and Failure Logic, the Control Laws and parts of the BITE routines are cyclically executed in an endless loop. The AFDS hardware interfaces transmit the inputs and outputs of the program to/from certain data memory locations in parallel to the program execution. Additionally to the program outputs sent to the CSAS and the different displays, signals at various stages of the computation can be monitored on the flight test channel. There is a variaty of input/output signals: digital parallel, digital serial, discrete, analog, synchros. In total there are more than 40 discrete, 20 digital/analog input signals and more than 150 discrete, 45 digital/analog output signals, relevant to the AFDS software.

3.2 Classification of applied measures

For safety critical systems like the AFDS naturally a lot of measures are taken to achieve highly reliable software and to assure software confidence. There are many different activities during the different stages of the AFDS software development. The most important are outlined below and classified according to [3].

a. First of all everything is used to make the software as error free as possible. Therefore constructive fault avoidance measures have been applied beginning at the earliest phase of the software development process down to the system integration phase. For example special emphasis has been put on systematic requirements analysis, careful specification, top down design, structured programming. Generally good software engineering methods are very important.

b. Then all kinds of dynamic tests - dynamic analytical fault avoidance measures - are applied on all levels to detect possible existing errors. Extensive dynamic tests are not only applied to the final integrated software package, but also to every software module during the software development.

c. Also static tests - static analytical fault avoidance measures - have been applied. Code inspections of the AFDS source code have been partially made. The AFDS source program listing has been visually analyzed and checked with the intent of detecting programming errors.

d. Furthermore fault tolerant measures have been taken. That means the AFDS software has been constructed in that way that certain possible software errors cannot advance to the program outputs, at least not to their full size. For example software limiters are built into the different places of the AFDS software keeping the effects of possible previous software errors to a minimum. Besides the most critical outputs are monitored by hardware authority limiters that restrict the output signals to a certain range.

e. Last but not least procedural fault tolerant measures are taken. For example the flight tests and the flight clearance of the critical automated flight modes are started at safe altitudes. Software errors would not result with a high degree of probability in a crash, because there would be enough time to switch off the automatic AFDS mode, to control the aircraft manually and to recover the aircraft from a critical flight manoeuvre.

This paper concentrates on the dynamic software test methods of point b., which are applied by MBB to the AFDS as delivered subsystem. The tests during the development phase - module tests, module integration tests - are the task of the AFDS supplier and are not described here.

The AFDS - hardware and software - has been developed by Marconi Avionics. The customer set up the system requirements and the system specification. The developer developed the system applying all possible quality assurance measures. After the AFDS computers have been loaded with the software they are shipped to the customer. Then a lot of subsystem tests and integration tests on different test facilities were executed by MBB. The system responsiblity is on MBB and therefore MBB has the greatest interest to test the AFDS system thoroughly.

3.3. Dynamic software test methods applied and test facilities available at MBB

3.3.1 Acceptance tests

These tests are executed on a test bench. The inputs to the AFDS are supplied with static voltages and bit patterns. Some outputs are measured and compared with predefined expected results. These tests should check above all the correct functionning of each single computer (material defect, production defects). Therefore every AFDS computer has to be subjected to this test. Indeed the AFDS software is indirectly tested by this method, but the number of the test points is too small to check the AFDS software thoroughly.

3.3.2 Closed loop rig tests

A rig system provides the capability of performing avionic system integration by realtime simulation. All avionic sensors, LRU's and other equipment are installed as real equipment or they are simulated - so as the aircraft dynamics - by a simulation computer. They are connected as on the aircraft. The various control panels, the control stick etc. can be used as in normal aircraft operation. The behaviour of this test facility is equivalent to real flight situations. A data handling computer monitors the inputs and outputs of the avionic equipment. Further details can be found in other publications [6].

The objective of closed loop rig tests is to evaluate the performance and hardware/software integrity of a system/subsystem under normal and abnormal flight situations. The flight tests are supported by simulating abnormal inflight occurances or answering test pilot questions. More in detail:

- The performance analysis tests in the case of the AFDS investigate the design of the AFDS software, the layout of the control laws and of the mode and failure logic. They check if the overall system requirements are met.

- The system behaviour has also to be checked under abnormal situations. Especially the ability of the AFDS is investigated to detect failures of lanes, interfaces and components and to react in a reasonable manner.

- Finally software confidence tests are executed on the rig. That means test procedures are applied which especially verify the correct programming and implementing of the control laws and the mode and failure logic.

3.3.3 Flight tests

Flight tests are executed when the rig tests have demonstrated that the system works with a satisfactory degree of confidence. The flight clearance is restricted at the beginning to a limited envelope until sufficient confidence is gained from flight experience. The flight tests are a final proof of the system performance.

3.4 Why build a new automated test tool

As a new link in this chain of tests and test facilities described above the Cross Software Test System (CSTS) has been developed. The objective was to evaluate the correct implementation of the AFDS software and to perform software confidence tests. The AFDS software should be tested as a hardware/software integrated subsystem to recognize possible interface or hardware problems.

Software confidence tests are very time consuming and expensive:
- Because of the multitude of the program inputs and their combination possibilities a lot of tests has to be executed to reach a satisfactory test coverage and completeness.
- All tests have to be repeated if the AFDS software is modified, even if the modifications affect only some modules. Side effects of the local modifications could influence other modules.
- Because of the costs involved a rig test should only be used for integration testing and not for finding errors in a line replacable unit.
- Testing is very time consuming and difficult in spite of automated stimulating and recording by a test computer. In the ideal case all test results must be compared with predefined expected outputs. If this principle is not applied, there is a chance that a plausible but erroneous result will be interpreted as a correct one. The cause is based on human psychology and the phenomenon that "the eye is seeing what it wants to see" [4]. The application of this principle to the AFDS is restricted by the complexity of the computations and the extent of the tests. Often expected results can be given only with great tolerances or they are derived from the results of a neighbouring testpoint definition.

Therefore we wanted to develop a new test tool, that executes the AFDS software confidence tests as far as possible automatically. Thus the number of the tests can be increased and the test coverage and quality can be improved without additional expense.

In the following pages this new automated test tool is described: The AFDS Cross Software Test System (AFDS CSTS).

4. DESCRIPTION OF CSTS

4.1 Principle of CSTS

The AFDS computers loaded with the software programs are coupled with a test computer, a PDP 11/70 (see Fig.2). All input/output signals of the AFDS are stimulated/recorded by hardware interfaces (digital/analog converters, analog/digital converters, digital interfaces, synchro signal converters).

A model of the AFDS software is executed on a PDP 11/70. It has been developed according to the dual programming method: The base of the software model is the specification of the AFDS software. But apart from that it is totally dissimilar to the AFDS software:
- Both programs run on different machines. The computer architecture of the PDP and the AFDS are totally different. The PDP uses floating point arithmetic, the AFDS fixed point arithmetic.
- The software model on the PDP and the AFDS program have been programed in different languages: The software model in the high order language C, the AFDS program in assembler.
- The design and the development process of the AFDS software and the software model were different.
- The programming teams were independent

Because of this dissimilarity the probability is very low that errors in the AFDS software and in the software model are in identical places and have the same erroneous effects.

Furthermore, because of the characteristic of floating point arithmetic and of high order languages some error sources are omitted in the software model. In floating point arithmetic you have normally not to care about overflow, scaling or accuracy problems. Programs written in an high order language tend to have fewer errors, because they are shorter and clearer.

Finally because of the software model programming method not only implementation errors could be detected, but also errors in the specification. The programmers were at the beginning of the CSTS development new to the AFDS software specification. They tried to understand the contents of the specifications completely and checked once again all formulas and descriptions critically. Ambiguities and unprecise formulations have been clarified in close contact with the AFDS system engineers. (Not recognized ambiguities of the specification are detected during the CSTS test at the latest). Then the programmed software model has been given to AFDS system engineers to make a code inspection.

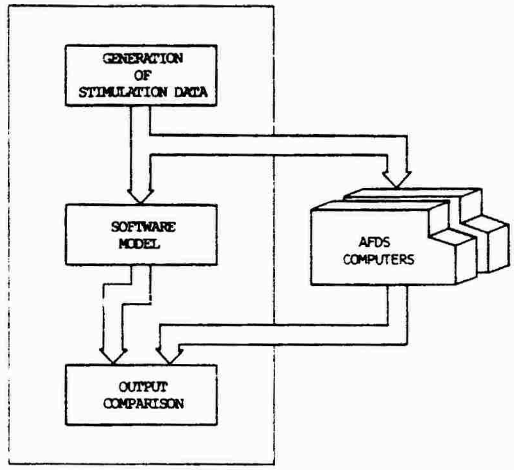

Fig.2: Principle of CSTS

A test driver stimulates the AFDS computers and the software model with identical inputs. It receives all outputs of the AFDS computers and compares them with the outputs of the software model. If it detects a discrepancy between a software model output and an AFDS output, it recognizes this as an error, breaks off the test and protocols the deviating results.

The error situation is manually analyzed to determine the source and the location of the error. The error can be either in the AFDS or in the software model. The erroneous program is corrected and the tests are repeated. The CSTS tests are finished, if all tests are executed without any discrepancies.

These tests are all executed in real-time. The CSTS automates all parts of a test as far as possible. The test execution and the checking of the test results is totally automatic. The stimulation data sequences don't have to be defined explicitly, but only the formulas for their generation. The analysis of a detected discrepancy is supported by the additional listing of all available intermediate results.

4.2 CSTS hardware structure

The core of the CSTS hardware is a PDP 11/70 computer, surrounded by a set of standard devices: 3 terminals for program development and test control, a type writer as operator console, a line printer for generating test reports, a magtape for system backup, and two 10 MB removable disks. A lot of special interfaces couple the test computer to the AFDS inputs and outputs: digital inputs/outputs, analog inputs/outputs, serial digital inputs/outputs and synchro outputs. All AFDS inputs and outputs are connected to the CSTS test computer. Even the power lines to the AFDS can be interrupted by computer controled relays. Thus power failure situations could be simulated and analyzed. The crossfeed signals between both AFDS computers are controled too. Additionally an 8-channel-recorder is installed to record selected AFDS or software model inputs or outputs. Also a special interface is installed that enables the synchronous execution of the AFDS and the PDP program.

4.3 CSTS software

4.3.1 Design principles

The most important design principles were to use a test language, to execute the total test in real-time and to construct the system hardware and software so universal, that it could easily be adapted to new requirements.

Each test is completely described by commands that are written on disk files. Therefore all tests are reproducable and exactly protocoled. The test commands are easy to understand. They control all test actions: They define the generation rules of the stimulation data, they adjust parameters needed during the comparison of software model and AFDS outputs (tolerances, masks), they select parameters and time slices that should be protocoled.

The real-time ability has been made possible by:
- Generating of the stimulation data at test execution time by interpretation of test commands
- Running of the software model at test execution time in parallel to the AFDS
- Comparing the outputs of AFDS and software model during the test execution, only deviating results are stored.

Therefore no disk or magtapes are needed to store the huge amount of data. The size of a magtape for example would only suffice to store half an hour of stimulation data, model outputs and AFDS outputs. Because of this real-time design no magtapes or disks have to be mounted or dismounted. The duration of the tests is not restricted by space or time limits. In addition this design concept delivers new possibilities to generate stimulation data. The AFDS- or software model outputs of the previous program cycle can be used to generate the stimulation data of the next program cycle. For example if the AFDS disengages, then a reengagement can be forced setting the autopilot engage request signal.

Because the software is table driven, it is easy to modify and expand. The hardware was also designed to be easily modified and expanded. Because of this flexible design the CSTS can be easily adopted to AFDS modifications or to new subsystem applications.

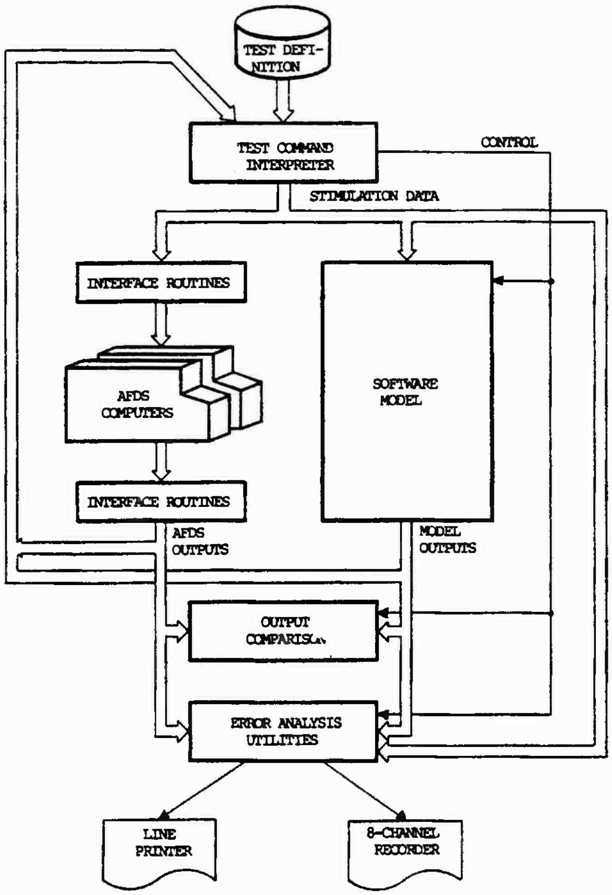

Fig.3: Software Structure of CSTS

4.3.2 Stimulation features

A great deal of the test commands are used to generate stimulation data. The main features of these commands are listed:

- all stimulation and output signals are named symbolically
- values in assignements are given either in units or in volts
- there is a command defining incremental or decremental changes of a stimulation parameter
- there are sinus or saw tooth functions to vary parameters continuously with freely adjustable frequencies and amplitudes
- the pressing of switches on the pilot control unit or the control stick can be simulated whereby the duration of pressing is adjustable
- lists of signals can be stimulated in all possible permutation sequences
- in arithmetic and logical expressions all standard operators can be used
- some signals can be automatically computed to inhibit sensor monitor trips in the AFDS
- if - then - else statements
- loops
- parallel execution of computation blocks

4.3.3 Features of output comparison

Normally <u>all</u> outputs of <u>both</u> AFDS computers are compared with the corresponding software model outputs. The outputs are compared after each AFDS program cycle. By special test

commands the following things are adjustable:
- Tolerances define the allowed deviations between digital/analog AFDS and software model outputs. The tolerances can be defined in percent of the maximum possible value or in volts. Deviations of a few percents have to be allowed because of the noise on the analog input and output signals.
- Single outputs can be excluded from the comparison. This was very useful during the integration phase of the CSTS.
- The number of tolerable successive errors, before an error is reported, is adjustable

A software error is assumed and the test is broken off, if the difference of any compared output pair is greater then the allowed deviation and it is present longer than the allowed number of successive errors. In addition to these standard checks special plausibility checks are freely definable. They are realized by if-then-statements.

4.3.4 Test analysis utilities

Besides the CSTS supports the analysis of the errors with some utilities:
- An error trace listing is automatically generated, if a discrepancy is detected. It lists all AFDS and software model inputs and outputs - inclusive of all available intermediate results - of a program cycle. The number of the protocoled cycles before and after en error is adjustable. The observed discrepancies are marked. At the top of this listing the test commands defining the test are printed and the test command is marked where the error was detected.
- The error trace listing can be explicitly generated on each location of the test
- 8 input/output signals can be recorded in real-time on an 8-channel-recorder. The signals and their scaling are selected by test commands.

5. EXPERIENCES GAINED DURING CSTS INTEGRATION

During the integration phase of the CSTS we had to solve some problems that are typical of such test tools. We wanted to allow only small deviations between software model and AFDS outputs so that the CSTS tests could be very sensitive. As preconditions for that we had to eliminate all secondary output falsifications resulting from the coupling CSTS to AFDS:
- The synchronisation between the test computer and the AFDS had to be exact. The interface delay times had to be taken into consideration.
- Problems originated from different algorithms and different precisions of arithmetic calculations. They were mostly located on testpoints outside of the normal flight envelope. Some modifications of the software model were made because of this.
- Noise on the analog lines could not be avoided. Therefore we set the allowed tolerances above these tresholds.

Although the use of the analog signals caused some problems, the inclusion of the hardware increases the quality of the CSTS tests. Not only coding errors, errors of the assembler, the compiler and the run time system can be found, but also faults of the interfaces and of the processor.

Absolute precondition for the analysis of the detected discrepancies was the availability of the complete system documentation and of results on the flight test channels and the crossfeed links. Otherwise it would have been almost impossible to determine the reasons for deviations. Therefore it is necessary to think of the test abilities already during a subsystem design.

6. EVALUATION OF CSTS

The CSTS fulfills all classic requirements of testing: All tests are completely documented. They can be exactly reproduced. The expected results are predefined. The tests are fully automatically executed. Thereby the number of tests can be significantly increased. The tests themselves are very rigorous, because <u>all</u> outputs are tested after <u>every</u> program cycle against very precise nominal outputs. The effectiveness of the CSTS has been shown by the detection of some minor, non critical errors. Detailed investigations about dual programming demonstrate the quality of such test methods [5], [7].

It was not intended to use the CSTS to replace the other tests or test facilities. A combination of different tests that complement each other provide greater assurance of correctness. The CSTS has been developed to test especially the correct implementation - software and hardware - of a safety critical subsystem and to perform software confidence tests as far as possible automatically. But also ambiguous formulations in the specification are detected.

The costs of the CSTS are in essential nonrecurring. Repeated applications in the case of AFDS modifications require scarcely additional expense. Only the software model has to be modified and the test procedures have to be extended by parts that test the new modifications. The other routines remain unchanged. The test execution itself is automatic as described above.

With small enlargements of the hardware the CSTS could be used for other tasks, for example for acceptance tests. Because of the universal design the CSTS could be reconstructed with low costs for other systems to be tested.

In conclusion it can be stated that the CSTS lowers in the long run the costs of testing safety critical subsystems increasing simultaneously the number and quality of tests. Certainly it could be applied to other subsystems of modern weapon systems.

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DISCUSSION

K.F.Boecking, Ge

(1) Can you test with this system that e.g. an additional $A = B + C$ will work well under all allowable numbers for B and C?

(2) In addition, can you make sure with the testing system that there will be no condition under which the AFDS runs into a dead end or hang up itself?

Author's Reply

(1) Because the tests run totally automatically the number of (B, C)-combinations can be increased at will without any additional costs.

(2) The architecture of the AFDS processor inhibits a hang up of the AFDS already. In addition the AFDS has been tested under a very high number of extreme conditions. Therefore the probability is very low that such problems remain undetected.

W.S.Bennett, US

(1) Have you done any dynamic frequency response testing between your simulated software and machine software?

(2) If you have, what evaluation have you had over a large frequency range?

Author's Reply

All tests have been executed dynamically. The input parameters have been varied with different frequencies. But because the simulated software and the machine software run synchronously we have got a one-to-one correlation.

N.J.B.Young, UK

My question is in three parts:

(1) Have you measured the effectiveness of your techniques, e.g. by using bug seeding?

(2) How often do apparent faults shown up by your system turn out not to be faults at all but due to i.e. differences between fixed and floating point arithmetic?

(3) When a fault is signalled, how much work does it take to locate its source?

Author's Reply

(1) We have just finished the development and execution of tests. Detailed investigations about the test effectiveness will be made in the near future.

(2) Discrepancies due to e.g. differences between fixed point and floating point arithmetic were mostly located on testpoints outside the normal flight envelope. Through slight careful modifications in the software model such effects could be avoided in the following tests.

(3) Because the history of all inputs, outputs and available intermediate results of AFDS and software model has been printed in the case of a fault, the source of the fault could be very easily located, mostly in less than one or two hours.

AD P002873

AUTOMATING THE TESTING OF SOFTWARE

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SUMMARY

Continuing growth in the number of high-integrity software-based systems is causing a corresponding growth in the problems of software testing (or, more generally, software validation). In recent years there has been growing interest in a variety of validation techniques but the problem of how to apply these in a practically useful, cost-efficient, automated form has not been resolved. This paper classifies some available techniques against a concept of automatability and identifies directions in which they can be improved for usefulness rather than for academic interest. One promising technique is 'symbolic execution' and the results of a detailed study are presented. A reduction in routine testing costs by a factor of two to three, as well as other benefits, can be achieved in many cases.

Introduction

Software for aerospace applications is algorithmic in nature : that is, it performs functions or solves problems by performing a finite sequence of operations, in this case a sequence of machine code operations in a computer. The concept of an algorithm is not new. It goes back at least to ancient Greece, and algorithms for arithmetic problems were well known in the Middle Ages. More recently the growth in the use of computers has led to an explosion in the number of algorithms, correct and incorrect, in use.

The number of software based systems for high integrity applications, for example aerospace spplications, is also expanding rapidly and is outstripping our sbility to vslidate such software. Three genersl spproaches have been taken to resolving this problem:

i) To reduce the need for software validation by better design techniques, the use of High Order Langusges and problem statement languages, the application of Quality Procedures during software design and modificstion, etc.
ii) To improve the effectiveness of traditional testing methods by standardisation, application of Quality Procedures, extension of the domain of testing methods (from the testing of routines through to the testing of entire softwsre systems), snd by attempting to <u>measure</u> the effectiveness of these methods. Within this approach we may include dual coding, hardware-in-the-loop testing, error logging and bug seeding.
iii) To introduce new methods for validating software. This includes what have become known as 'proving' techniques, such as the use of assertions, to give proofs of software correctness in the same sense as mathemstical theorems can be proved. 'Proving' techniques are often distinguished from 'testing' techniques in that the latter are noted to be sble to demonstrate only the presence of errors, not their absence. This distinction will not be emphasised in this paper and indeed is at present of little practical interest - progrsms for which correctness 'proofs' have been published have been shown to have flaws (Reference 1).

This paper is concerned with the third approach and with conventional testing from the viewpoint of cost-effectiveness and automatability. It should however be noted that certain developments in design techniques, especially the introduction of new High Order Languages rich in language facilities, may sctually produce software which is harder to validate. An extreme example is given in Reference 2.

The 'Perfect Automatic Softwsre Testing Device'

Let us first formulate a concept of what would, in a perfect world, be a 'perfect automatic software testing device'. Then we can strip away some of its characteristics in order to formulate an objective, no longer perfect but still useful, against which we can assess our current techniques, and which we may be able to achieve in prsctice.

i) The perfect device would be a black box, into which we would feed our software and out of which would come a test report and a statement of correctness or incorrectness.
ii) The perfect device would act essentially instantaneously and would require no operator intervention or action.
iii) The perfect device would accept software in sny form in which it already exists and would require no additional input.
iv) The output would be comprehensive but brief and in a generally acceptable form. If an unmodified and a modified version of the software were both input the difference in their effect would be immediately apparent from the output.
v) The input software could be of any type, for any function, and of any length.
vi) The device would detect errors of any type, including both specification and implementation errors, and any data-dependent errors which might occur in just a small part of the data domain.

vii) The device would not only detect errors in the software presented to it but would also highlight problems in integrating this with other software.

An Achievable Objective?

Now let us reduce the characteristics of the perfect device to try to formulate an achievable objective which is appropriate to our requirements:

i) The objective is a simulation package, into which we would feed our software and out of which would come a test report in the best possible form.
ii) It would produce its output speedily and require little operator involvement.
ii) It would accept software in machine code (runnable) form and a minimum of test specification information.
iv) The output would be comprehensive but brief and in a form suitable for Quality auditing. The output would readily show the results of any software modification.
v) The input software could be usefully long. Modern design techniques suggest a preferred maximum software module size of fifty statements and this must be the minimum achievable. We may restrict the software to be tested to that suitable for high integrity defence applications (for example), so that if we wish the software will have to be well structured and not include any inherently unsafe constructs. (For example, WHILE loops have no predetermined limit of execution times and may be considered inherently unsafe; and are often forbidden in high integrity software. FOR loops, by comparison, are not necessarily inherently unsafe). We may restrict the software source language to assembly code or a Defence standard High Order Language such as CORAL 66 in the UK (Reference 3) initially for a Defence standard processor. Given these restrictions it is an objective that a high proportion of software modules can be tested.
vi) vii) The achieveability of these characteristics of the perfect device will be left for consideration until the end of this paper.

In summary, the objective is a form of software validation, widely but not universally applicable, for use on Defence projects, automatable, with good error coverage and convenient output format.

Automatability Concept

It should be emphasised that the concept of automatability of testing applies to all aspects of testing, including the preparation of software for automatic testing and the examination of output. There is little benefit in an 'automatic' testing process which requires for example extensive and costly preparation of a test specification or gives an output which is less comprehensible than the original code. Automating the teating of software involves reducing all aspects of the work of the human tester while increasing the understanding of the operation of the software provided by the test output. Since the quantity of test preparation and results examination work is directly related to the required degree of understanding of the software module by the human teater, we can define (in subjective units):

$$A = \text{Degree of automatability achieved} = \frac{\text{Insight gained from test}}{\text{Work by tester required}}$$

We shall find that, contrary to expectation, very high values of A are achievable (techniques achieving this will be termed 'highly A-automatable'). We now assess some software validation techniques against this concept of automatability.

Conventional Numerical Testing

A software module may be represented (fig. 1) as a process by which inputs are converted to outputs. Conventional numerical testing involves running the module with predefined input data and comparing the outputs with predefined supposedly correct results. In practice the modules may be run on target hardware using an in-circuit emulator or in a cross-simulator on another machine (to take two examples) but this does not affect the principle of the test. The test may regard the module as a 'black-box' and only be concerned with inputs and outputs; or as an internally examinable 'white-box', and additionally inspect intermediate reaults, paths followed, etc.

The writing of a test specification is a task of significant size, and the maintenance and rewriting of test specifications throughout the modification life of a module represents a considerable part of life cycle costs. Further, modifying a test specification to correspond to a modified module is a highly error-prone process.

It is very difficult to relate testing effort to achievement - to know 'how much is enough'.

It is often preferred that there be independence between those implementing, those specifying and those performing tests on the module. But when the test is performed it is highly probable that there will be a discrepancy between the supposedly correct and actual results. Resolving such a discrepancy involves examining not only the module implementation, but also possibly the test specification and even the module specification. This compromises the independence of the testing process. It is also likely that thoae working in the same environment, to the same procedures, will make similar assumptions. Their 'independence' is therefore to a considerable extent illusory.

Further, with these methods of testing there remains the possibility of an undiscovered data-dependent error. The test specification and test results are usually large documents and therefore difficult to examine in detail and expensive to archive.

The degree of A-automatibility achieved is therefore low.

Dual Coding

In dual coding the module specification is implemented twice, once for the target machine and a second time, perhaps in a different language on a different machine. Dual coding itself requires more work but reduces the need for test specifications as outputs from the two versions can be compared. However the main criticisms of conventional numerical testing also apply to dual coding.

Spectral Observation and Hardware-in-the-Loop Testing

In spectral observation very large quantities of input data are generated (eg. by some pseudo-random scheme) but only statistical information is collected about the outputs. The output spectrum (fig. 2) is then examined for apparent anomalies. This technique may give insight on data-dependent errors but only detects very particular types of anomaly. Hardware-in-the-loop testing with performance measuring and anomaly recording is usually preferred; but as with dual coding the detection of a discrepancy in itself gives little information on where or why it has occurred.

Code Reading

Of the conventional techniques assessed in this paper, code reading by a second party gives the greatest improvement of insight into the operation of a module, though it requires considerable work to achieve this. We can regard the other techniques assessed below as being an automated or assisted version of code reading.

Control-Flow and Data-Flow Analysis

(A good account of this and other techniques assessed below is given in Reference 4). The basis of control flow analysis is that each program should have:

i) A single, initial START (or ENTRY) statement with no predecessors.
ii) One or more final HALT (or EXIT) statements with no successors.
iii) No jumps to non-existent labels.
iv) No labels to which no jumps exist.
v) No statements which 'cannot' be reached from the START statement.
vi) No statements from which a HALT statement 'cannot' be reached.

('cannot' usually meaning the non-existence of any path. But even if a path existed, it might not be feasible, i.e. the path condition might be logically false).

As is well known, this form of analysis can be performed automatically by certain compilers and other utilities. Such an analysis is only a very partial test but it requires no user effort and can highlight apparent anomalies.

Data flow analysis checks that:

a) Variables are not used before being given a value (or more usually before being able to be given a value along at least one feasible path).
b) Variables once given a value can be used (in particular before being given a new value).

These checks highlight anomalies which may indicate errors of understanding (eg. data scope errors), misspellings, confusion of names and omission of statements.

Again, this analysis may be able to be performed automatically by a compiler without user effort.

These analyses are highly A-automatable, providing user insight post-test without requiring any pre-test insight. They are, however, of extremely restricted usefulness without further extension.

Flow-Chart Reduction

Dijstra-structured programs can be 'reduced' to a single statement by iteratively reducing recognised structures (sequences, selections, iterations) in the code to single statements. Other programs may not be reducible in this way (fig. 3). Automated reduction can be achieved (Reference 4) though with considerable algorithmic difficulty for larger programs (Reference 5) and the process can provide considerable insight into the software structure that has actually been implemented, without user effort. Again this method is highly A-automatable.

Acyclic Segment Analysis

This technique can be applied to program segments which contain no indeterminate loops or in which all such loops can be 'reduced' to a single higher order statement. All the possible paths through the segment (which contains conditional expressions) are identified and are listed separately with the logical condition under which the path will be executed.

A proportion of the paths will not be executable because their logical conditions are always false and these need not be tested. In a study by Knuth (summarised in Reference 4) only a few percent of all paths were executable, and the clarification of the logical conditions for the remainder may suggest simplifications and highlight errors or neglected possibilities. Studies on high-integrity engine control software at DOWTY ELECTRONICS suggest that between one and two thirds of paths in typical routines may not be executable.

This method is mainly a guide to how to conduct further testing, and is therefore not comprehensive, but has high A-automatibility.

Assertion Techniques

Assertion techniques (sometimes just called formal program proving techniques) require the user to make precise statements (assertions) of what is true about the program variables at different points in the program. The assertions are then subjected to transformations corresponding one-to-one with the code statements as they 'travel' through the program. It can then be checked that the transformed assertion from one point is precisely the assertion at a second point.

Assertion techniques are of major academic interest since they are similar in form to some mathematical theorem proving techniques and they are the only general software proving techniques yet known capable of demonstrating the correct termination of indeterminate iterative (eg. WHILE) loops. But it is not at all certain that they are useful in practice. Firstly, WHILE loops can often be avoided in high integrity software by using non-iterative or determinate iterative (FOR loop) methods, and in many cases occur only in a small number of modules. Secondly, assertions are extremely difficult to define since they should be exactly as strong as is required to contain all the required characteristics of a program. Thirdly, assertion proofs are usually proofs at a High Order Language level and therefore may not be valid at machine code level. Other objections are given in Reference 6.

Assertion techniques at present have very poor A-automatability due to their requirement for major user involvement. To resolve this it would be necessary to devise techniques for automatic generation of assertions from program code.

Symbolic Execution

Symbolic execution of a module is an advanced simulation technique in which input variables are assigned symbolic, not numeric, values. The results of such simulations are algebraic equivalents to the program paths followed. These results can be compared directly with the module specification, not the test specification for essentially no test specification is required (no values need be specified for symbolic variables).

Symbolic execution was identified by DOWTY ELECTRONICS as a technique which was potentially both comprehensive and highly A-automatable provided that certain problems in implementing the technique could be overcome. A major research and development programme was therefore initiated to achieve both high automatability, low cost-of-use, and improved testing coverage compared with conventional numerical testing. The remainder of this paper gives an account of what has been achieved.

(Note that this method is quite distinct from what is sometimes called 'symbolic debugging' i.e. conventional numerical testing in which variables are accessible not by location but by their High Order Language names).

Basic Idea

The basic idea of symbolic execution can be illustrated by a simple example. Consider the program fragment in some arbitrary High Order Language:

```
X = Y + Z ;
```

Suppose we wish to test this by conventional numerical methods. We would assign Y and Z numerical values, say 2 and 3. We then execute the program fragment and achieve the numerical result 5 (we hope). We then repeat the test for other values until we are satisfied of correctness.

In symbolic execution we assign to Y and Z not numerical values but symbolic values, 'y' and 'z' say. The machine code form of the program fragment is then symbolically executed and the result is a symbolic string 'y + z' (assigned to X) which is readily identifiable as algebraically equivalent to the original High Order Language version. (Since we symbolically executed the machine code version of this program we have effectively de-compiled that version back into the High Order Language). Since 'y' and 'z' could represent any numerical value we have tested the fragment for all numerical values.

A software module will typically contain conditional expressions involving symbolic values and there will therefore be many paths through the module, each with its own logical path condition on the input variables (compare Acyclic Segment Analysis, above). In general, then, a symbolic execution output will consist of a set of results, one for each path, consisting of a path condition and symbolic strings assigned to locations, typically in the form:

```
Path condition 1    : a = '- - -'
                      b = '- - -'
                      - - - - - - - -
Path condition 2    : a = '- - -'
etc.
```

The main difficulty in applying this technique is that the number of paths may be very large. Since every path must be symbolically executed the volume of results could become unmanageably large. It is possible, though not necessarily desirable, to identify and eliminate infeasible paths during symbolic execution, but the general data reduction problem is not fully resolved by this.

Comparison of Approaches

Symbolic execution is not a new idea and it is useful to compare the DOWTY ELECTRONICS approach to this technique with published studies.

Howden, in an empirical comparative study of software validation techniques (Reference 7) found symbolic exacution to be a relatively effective testing technique, but regarded it as an expensive technique to use. (Not in agreement with the results of the DOWTY ELECTRONICS study).

Several studies (referred to in Reference 4) have been made of the possibility of automating symbolic execution of programs at the High Order Language level (not machine code level). In this approach the symbolic values are assigned to High Order Language data types which could, for example, be multi-word floating point. Their conclusions are in accord with Howden. (I agree that this is a useful technique for testing at a later stage, after symbolic execution at the machine code level, effectively decompiling the machine code, has been performed).

Carter et al (Reference 8) applied symbolic execution to microprograms, observing that all data types could be broken down into bit arrays (and therefore arrays of symbolic values, one for each bit, would be required). In this study data reduction was performed whenever a new expression was created. The suthors were able to study microprograms of considerable complexity.

The DOWTY ELECTRONICS approach exploited modern developments in software design and the characteristics of the type of software (high integrity software, for engine control for example) of major concern to the company (Reference 2). Effectively only one data type, the machine word length (16-bit) variable, was considered for the majority of the study. (Though this could represent either integer or fixed point real variables. This is also in accordance with the general approach embodied in the UK Defence standard language, CORAL 66, Reference 3). No attempt was made to perform data reduction until after the symbolic execution process had been completed and all paths, feasible and infeasible, were executed. The testing of infeasible paths is important since a software modification may have the unintended effect of making an infeasible path feasible, and this should be immediately apparent on comparison of the two sets of symbolic execution results. This approach exploits the modern quality requirement that modules should be of small size will a manageable number of paths.

Only input variables were made symbolic (refer fig. 1). Local variables and constants were handled numerically where possible but were allowed to form parts of strings, for example 'y + 7'. This hybrid approach had considerable advantages of ease of use and cost reduction.

At an early stage in the DOWTY ELECTRONICS programme it was realised that symbolic execution could not only provide effective decompilation of machine code programs but could also be used to trace the flow of data into (sometimes undesired) areas. This aspect will be desci ibed first.

Data Tracing

In real-time recursive software the tracing of data items on successive iterations is a serioue problem. For example, it should be checked that initialisation and exception handling are correctly performed and that initialisation/exception data disappear from the syetem after an appropriate number of recursion cycles. It should also be checked that no extraneous side-effects such as the corruption of other data areas can occur.

Fig. 4 shows as a simple example a routine for updating a three-deep stack of previous data values. On each recursion this stack is updated with the latest value. Fig. 5 shows the result of a simple error which causee the stack to be only partially updated. This error would normally be found by conventional testing. But consider fig. 6. In this case the module specification has been mieunderstood and the data stack grows with potentially disastrous results, possibly after a considerable elapse of real time. Whether this would be detected or not depends purely on the test specification - and a test specification which did not detect this error would be unlikely to be recognised as inadequate by Quality Proceduree.

A generally unresolved problem in reel-time software at least in practice is to prove that asynchronous tesks cannot corrupt each others data areas. Consider for example a low priority task which is interrupted and suspended; one or more other tasks are run and the low priority task is then restored. We wish to ensure that the operation of the suspended task has not been corrupted. This requirement can be written in general terms as:

$$I^{-1} H I M = M \qquad \forall H \in \mathcal{H}, \forall M$$

where M is the mechine state before interrupt (more exactly, that 'part' of the machine state relevant to the interrupted task), I is the process of interruption and suspension, and $\mathcal{H}$ is the set of all possible transformations associated with the higher priority task or tesks. By exploiting the characteristics of symbolic execution (tracing of data by symbolic value and execution of all possible paths) the user can identify the data interactions between tasks, if any. The details are left to the reader, who is advised that he will discover multiferious problems but also multifarious solutions using the power of the symbolic execution concept.

Algebraic Results (and Effective Decompilation)

As well as providing data tracing facilities, symbolic execution provides formulae, each equivalent algebraically to a program path.

The output from a simple error-counting routine of thirteen instructions is shown in tree diagram form in fig. 7. On either of two error conditions the routine increments en error counter, limiting at three. If there is no error the routine decrements the counter, limiting at zero. In pseudocode:

<u>if</u> (bit 1 of C = 1 OR bit 1 of B = 0)

<u>then</u> (200) : = Minimum of (3, (200) + 1)

<u>else</u> (200) : = Maximum of (0, (200) - 1)

<u>endif</u>

where (200) is the contents of location 200, the error counter. (200) was given the symbolic value a end the symbolic execution results are given in fig. 7.

These results ere now examined es follows:

i) The union (logicel OR) of all the peth conditions is logical TRUE. This is merely e check on the testing process itself, to determine that all peths have been symbolically executed. In this cese ell peths ere feesible. Now each peth in turn is compered with the pseudocode definition of the routine.
ii) Peth 1
(200) : = Min (3, e+1) = 3 es expected since $e \geq 2$
iii) Peth 2
(200) : = Min (3, e+1) = e+1 es expected since $e < 2$
iv) Peth 3
Conditions $e \neq 0$ is not sufficient if 'e' cen teke ell possible velues (both negetive end positive). When 'e' is negetive e-1 will be negetive end Mex (0, e-1) should be 0, but the result indicates e-1 will be chosen. Either extre informetion on the input range of 'e' should be included in the routine definition or the routine should be re-coded defensively.
v) Peth 4
(200) : = Mex (0, e-1) = 0 es expected since e=0
vi) Peth 5
(200) : = Min (3, e+1) = 3 es expected since $e \geq 2$
vii) Peth 6
(200) : = Min (3, e+1) = e+1 es expected since $e < 2$
viii) The results should elso be exeained to determine the effects of in en erithmetic or comparison operetion (see elso Reference 2).

Cost Comperison

In the study the symbolic execution test was performed semi-eutometically using e numericel simulator with operetor intervention to record symbolic intermediate results according to e formelised (end therefore eutometeble) schedule, end wes compered with conventionel numerical testing. The results ere shown in Teble 1. Note thet even in semi-automatic form symbolic execution comperes well with numericel testing; end in e projected fully automated form it comperes extremely well. The physicel size of the results wes elso much reduced. The tester wes not previously femilier with symbolic execution and required treining of approximetely three hours.

Cepebilities

As part of the DOWTY ELECTRONICS study, symbolic execution wes applied to typicel software taken from existing engine control epplicetions. The study found thet:

i) The comperisons in Table 1 generelly remeined velid.
ii) Symbolic execution could be applied to lerger softwere modules of up to fifty instructions with ease; end up to seventy-five instructions typicel maximum with difficulty at the present stege of development of the technique. (The size problem

only arises due to additionel conditional stetements increasing the number of peths. The same problem exists with numerical testing).

iii) The visibility of the test results was better than for numerical testing (mainly due to reduction in their size).

iv) 70 to 80% of software modules can be tested eiher wholly or with parts separately modulerised (elso required in these cases with numerical testing).

v) No fundemental problems were encountered. For effective use the technique requires the use of speciel notation which was developed during the study. A major achievement was to solve the problem of recording condition register results. The notetion was designed for equal convenience for eutomated computer handling and for results presentation.

vi) The approach of performing the symbolic execution first without data reduction (e.g. elimination of infeasible paths) was confirmed as best.

vii) It was found that the technique hed several unpredicted benefits arising from the extra insight it provided into the operation of the implemented software module (i.e. the method is highly A-automateble). Exemples from particular cases are:

* Recognition that an apperently single function module could be divided into two separate modules each with fewer inputs and outputs (relevant to design for testability).
* Highlighting of date range or initialisation requirements (as found for the simple error counting routine, above).
* Highlighting of specification errors. In some cases this resulted from the high visibility of the test results when the comperison with the module specification was made, but in other cases the tester stated from a subjective judgement of the test results (without referring to the specification) that a module was 'obviously wrong'. This aspect of the psychology of testing is not yet understood.

Conclusions

The particuler advantages of symbolic execution are:

i) The enforced testing of every peth through the program module under test.

ii) The detection of dete-dependent errors.

iii) The highlighting of initialisetion and data range requirements and some specification errors.

iv) The effective elimination of test specifications which are very time consuming to prepare and difficult to updete without error.

v) The 'objectivity' of the method in the sense that the number of tests is not et the discretion of the tester. This mey be compered with the 'how much is enough' problem in numericel testing.

vi) The testing at mechine code level of code originally written in essembly code or e High Order Language. (This provides protection against compiler errors).

vii) The visibility of results (especially when investigating the effects of modifications), and in particular their relatively small volume.

viii) The ability to trace data items and investigate cross-corruption in a multi-tasking real-time system, providing a test facility for integrated software systems.

ix) High A-automatebility.

x) Wide, though not universal, applicability.

xi) Cost effectiveness. Even the semi-automatic method compares well with conventional numerical testing. The study indicates that full autometion will provide a reduction in software testing costs by a factor of two to three for modules of typical size.

These characteristics can be compared with those of the 'perfect automatic software testing device' and ths objective for achievement described early in this paper. Symbolic execution has been shown to compare very well in its area of application.

DOWTY ELECTRONICS are currently preparing the eutomation (the 'productionising') of the techniques already developed into a symbolic execution testing package for Defence applications.

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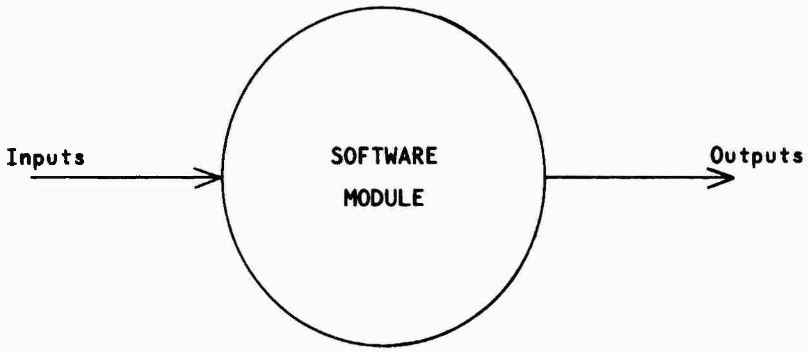


Figure 1 Data-flow description of software module as process

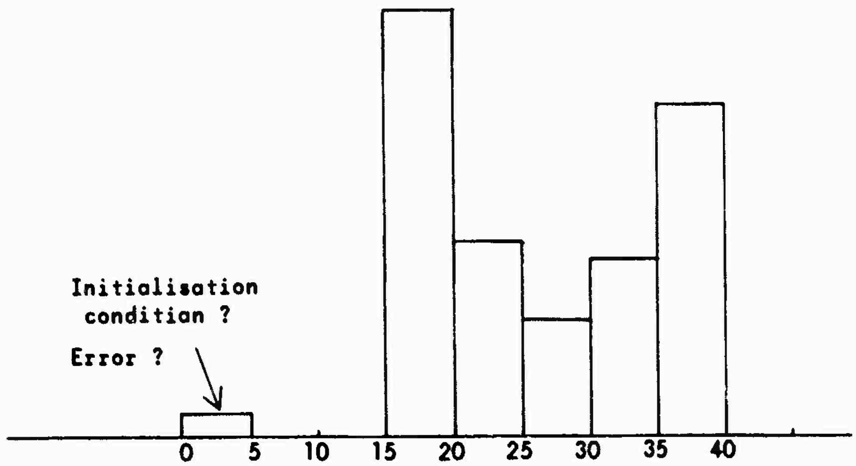


Figure 2 Spectral observation - range of outputs

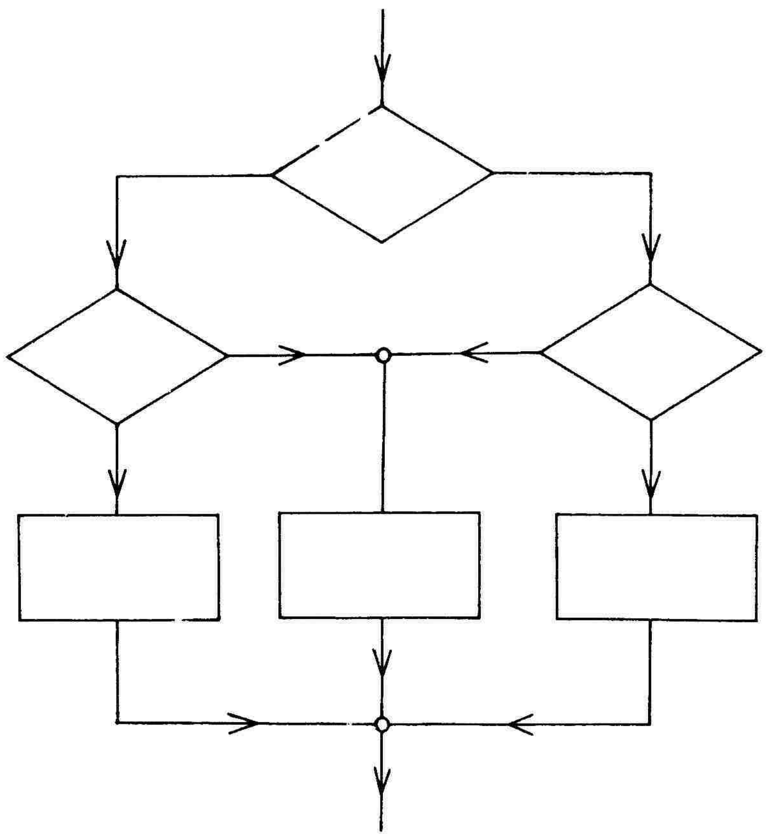


Figure 3   Non-reducible flowchort

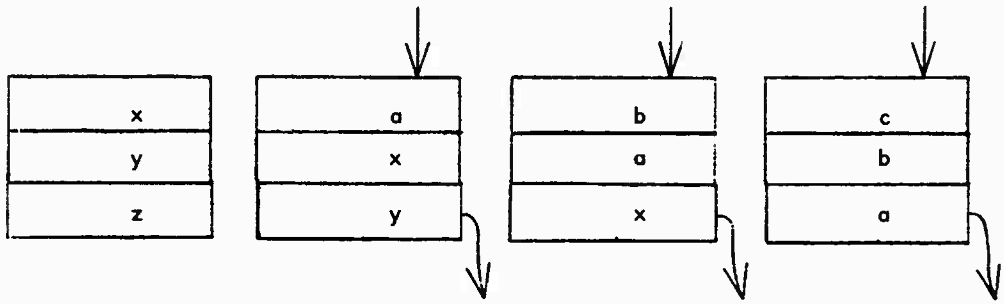


Figure 4   Successive recursions of a data stack updating routine

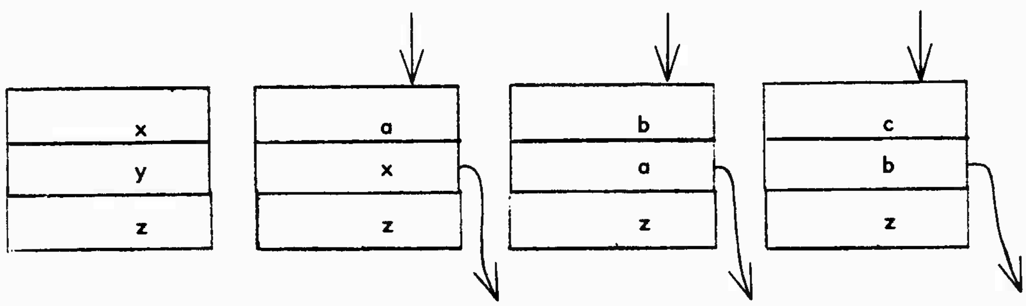


Figure 5   Successive recursions - error 1.

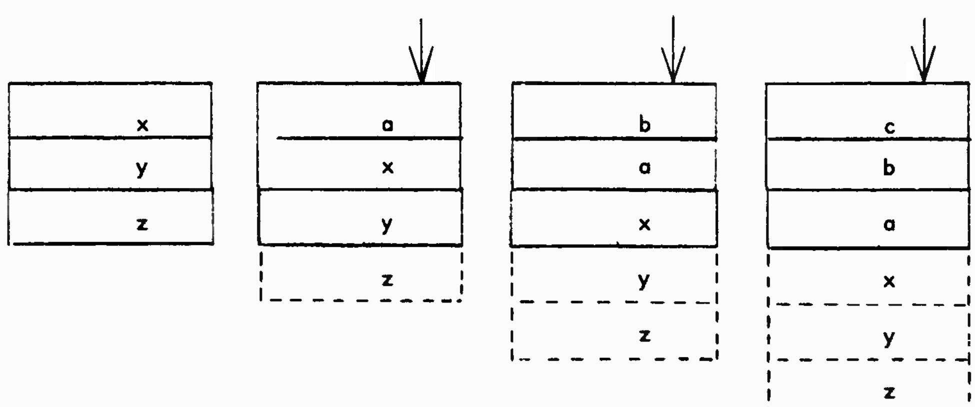
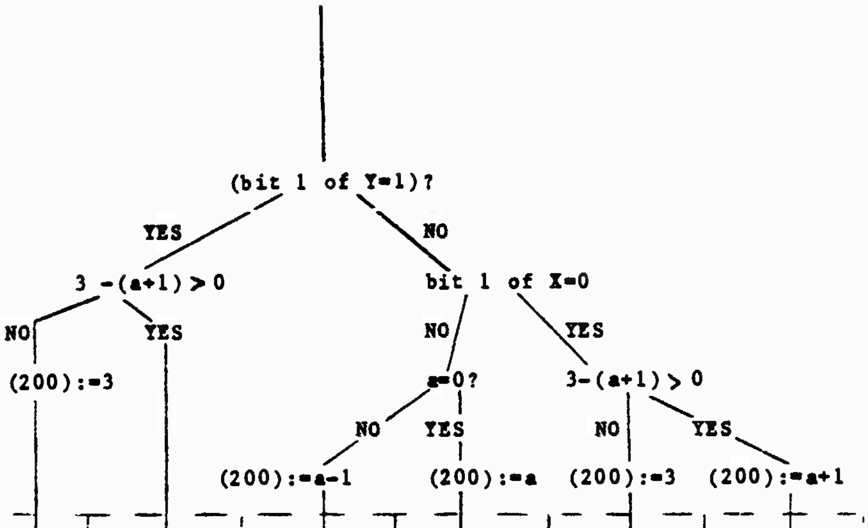


Figure 6   Successive recursions - error 2.



Path No.	1	2	3	4	5	6
Path condition	(bit1ofY=1) .AND. (a ≥ 2)	(bit1ofY=1) .AND. (a < 2)	(bit1ofY≠1) .AND. (bit1ofX=1) .AND. (a≠0)	(bit1ofY≠1) .AND. (bit1ofX=1) .AND. (a=0)	(bit1ofY≠1) .AND. (bit1ofX=0) .AND. a ≥ 2	(bit1ofY≠1) .AND. (bit1ofX=0) .AND. a < 2
Path result	(200)=3	(200)=a+1	(200)=a-1	(200)=0	(200)=3	(200)=a+1

Figure 7 Tree diagram of symbolic execution test showing path conditions and results along each path.

Technique	Test Specification & Command File Preparation (Minutes)	Simulation & Re-Specification Cycle (Minutes)	Results Checking and Report Generation (Minutes)	Total Time (Minutes)	Result Size (A4 Pages)
Symbolic Execution (semi-automatic)	15	45	60	120	3
Symbolic Execution (fully automated) Projected	15	10	40	65	3
Numerical test (6 data sets)	75	30	25	130	6
Numerical test (16 data sets)	90	60	15	165	12

TABLE 1 COMPARISON OF SYMBOLIC EXECUTION AND NUMERICAL TESTING

(Note: Numerical simulation was performed using UK Ministry of Defence approved cross-simulator)

DISCUSSION

A.O.Ward, UK

Is there a limit to the size of module that the method can be applied to?

Author's Reply

Our objective was that the output from a symbolic execution test of a module should be comprehensive but brief and provide insight to the tester; in particular we wanted to improve on what could be achieved using conventional numerical testing. Using symbolic execution in "effective decompilation" mode, the complexity of the test output grows with the size of the module being tested, since additional conditional statements increase the number of paths to be tested. (The same problem exists with conventional numerical testing). Tests on typical modules have shown that symbolic execution ceases to be useful beyond a module size of 75 instructions at the present stage of development of the technique; typical modules of 50 instructions can be handled with ease. This is sufficient for Defence quality software modules. The majority of our work has been with software written in assembly code but initial investigations suggest that the figures for High Order Languages are similar, even though one HOL line equates to several assembly code instructions (but may not introduce additional paths). It is possible that future development of the symbolic execution technique may extend the maximum module size, but I think it is more important now to concentrate on incorporating automated module testing into schemes for automating the testing and validation of sub-systems and complete software systems: – but these schemes are still under development.

A DYNAMIC APPROACH TO MILITARY AVIONICS SYSTEMS TESTING

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SUMMARY

In the successful development of major aircraft projects such as Jaguar, Tornado IDS and Tornado F Mk 2, the Warton Division of British Aerospace PLC has accumulated a great deal of experience in avionic systems development testing.

The pre-flight ground test philosophy ~~adopted~~ is based on the construction of an avionics systems development rig. Although the rig concept remains central to our philosophy, rig testing techniques have ~~had to~~ change as ~~the~~ avionics systems have increased in complexity and influence throughout the aircraft.

The techniques presently employed are made possible due to two main factors; ~~namely~~

(1) The adoption of an integrated approach towards the use of and interaction between the avionics rig and other development facilities.

(2) An increase in the use of computing for ~~the~~ data acquisition and simulation tasks.

This has resulted in a shift in emphasis from static to dynamic system testing and the avionics development rig for the Tornado F Mk 2 is capable of simulating flight.

Thus, it is possible to exercise the avionics systems throughout the aircraft mission envelope on the rig before flight testing begins. This capability represents a considerable cost saving in ~~the~~ development of ~~the~~ avionics systems since reductions in the aircraft flight test programme have been achieved and the flight testing time is being used more effectively.

The dynamic testing technique and its advantages form the basis of this paper which describes the Torndao F Mk 2 avionics rig facility and its operation.

1. INTRODUCTION

The development of an avionic system for the modern military aircraft is a lengthy process including many hours of system testing, both on the ground and in the air. The overall objective is of course to prove that the system meets the specifications and functions as advertised. In order to reach this goal, from the initial design phase through to the delivery to the customer, BAe Warton utilise numerous development facilities including :

Mathematical Modelling
Flight Simulators
Avionics Development Rigs
The Flight Test Programme

Each of the above plays a dominant role at some stage in the development process, however, there has always been interaction between these areas throughout this entire period. Whilst this interaction has always been present it has until recent years existed as a data flow, the facilities themselves remaining essentially independent.

To meet the demands of the Tornado F Mk 2 development programme a more integrated approach was adopted towards the use of these facilities. This resulted in the production of a much enhanced avionics development rig and significantly increased interaction between the rig, the aircraft and the mathematical modelling process. This integrated approach plus nn increase in the use of computing for the data acquisition and system simulation tasks made it possible to 'fly' the avionic system on the ground test rig.

This capability represents a significant cost saving in the development of the avionics system since flying time on the rig is much less expensive than actual aircraft flying time.

A brief account of the historical background to the present test philosophy is given and the concept of the avionics development rig is introduced. Particular emphasis is then placed on a description of the Tornado F Mk 2 rig and its operation. The advantages that have already been achieved through the use of dynamic testing techniques are presented and an indication of how this concept may be developed for future use is included.

2. HISTORICAL BACKGROUND

At the start of a new aircraft project the avionics rig test programme incorproates hardware integration, system development including hardware and software, and system clearance for flight. The major part of this programme is undoubtedly that which concerns the development and proving of the operational flight software. This is an ongoing task which continues throughout the rig life cycle as the operational software is updated, refined and enhanced to accommodate new system developments. For any new aircraft project, therefore, the extent and complexity of the operational flight software is a significant factor when considering both development programme timescales and the manpower requirements. The rig test philosophy adopted for the Tornado F Mk 2 project was based on previous experience gained through successful development of the Jaguar and Tornado IDS aircraft.

Jaguar

The Jaguar aircraft was designed in the mid 1960s and its avionics system is relatively simple by todays standards. The system was built around a Main Computer containing 8K of core store which housed the operational flight software. The system testing philosophy adopted on the Jaguar avionics rig involved a division of the flight software into manageable sections dealing with specific moding or mathematical equations. Each section was then statically tested on an individual basis. The results of these tests were compared to calculated theoretical results derived from the software design documentation. Since this testing was essentially static in nature only selected points of the operational envelope were covered. To exercise the software in a truly dynamic manner it had to be flown and consequently the aircraft had to be used as a software development tool. Although the ground testing satisfied the 'safe-to-fly' standard numerous problems were encountered during flight. These problems were then investigated on the rig which often took considerable time and effort because the in-flight conditions could not be easily reproduced. Once a problem was resolved and corrective action taken the aircraft was again used to ccnfirm the solution.

Thus the aircraft flight test programme had to take into account the need to devote flights to system development before concerning itself with system operational assessment, ie the aircraft was used to achieve the 'works as advertised' condition before it could address the problem of :

How well does the advertised system perform its task ?

Tornado IDS

This aircraft was designed during the early 1970s and like the Jaguar its avionics system was built around a Main Computer. However, the Tornado avionics system was both more extensive and complex than that for its predecessor. The operational flight software was resident in the Main Computer containing 32K of core store ie four times the capacity of that on the Jaguar. The software test philosophy adopted for the Tornado was essentially the same as that for the Jaguar, hence, the system development timescales expanded beyond those previously experienced. The Tornado aircraft had to be used to assist in the development of the flight software because this was the only way to dynamically exercise it.

To assist in the rig testing of the avionics system a Data Acquisition and Simulation System (DASS) was developed. The DASS was required to monitor and log the digital data that represented the major data flow on the avionics system. Other data forms such as discrete, analogue and syncho signals were also accommodated. Simulation of the data formats and types was also possible but limited to signal generator type functions.

As the development programme progressed the need to expand the data simulation and the data acquisition capabilities began to emerge

Tornado F Mk 2

The advent of the Air Defence Variant of the Tornado brought about a significant change in the avionics systems development testing philosophy. This was due to a number of reasons but chiefly the following :

(1) Unlike the previous two aircraft which had predominantly air to ground roles the Tornado F Mk 2's prime role was air-to-air. Hence the emphasis in weapon aiming was different and more complex in content. In order to test the weapon aiming system the presence of target data was essential.

(2) The avionics system was built around a Main Computer with a core store of 64K ie eight times that on Jaguar and twice that on Tornado IDS.

Development of the avionic system using established techniques with inherent increases in timescales and manpower was considered unacceptable.

Experience of the Tornado IDS programme had generated the idea of dynamic testing on the rig, however, it was realised that this could only be achieved by enhanced simulation and data acquisition capabilities. It was at this stage that the techniques employed in the Flight Simulator and Mathematical Modelling areas were essentially integrated with the avionics rig facilities. From the Flight Simulator came the well established technique of driving an aircraft aerodynamic model from representative flying controls. From the Mathematical Modelling process came the required avionics system simulations.

This integrated approach resulted in the development of a much enhanced DASS for the Tornado F Mk 2 avionics development rig which gave the rig a fully dynamic capability. This made it possible to actually fly the avionics system on the ground test rig executing navigation tasks and operating the facilities of the weapon aiming system.

3. THE AVIONIC SYSTEM DEVELOPMENT RIG

In order to prove the avionic system it has to be flown and exercised throughout its entire operational envelope. Before this can be attempted, however, sufficient confidence in the system design, its operational performance and its integrity must be achieved to comply with a safe-to-fly standard. To reach this standard the avionic system itself is subjected to a pre-flight ground test programme on the avonics system development rig.

This rig plus suitable support equipment provides a facility on which the following objectives can be achieved :

(1) Validation of avionic equipment interfaces

(2) Development of the system to a safe-to-fly standard

(3) Flight back-up

(4) System familiarisation for aircrew and ground crew

(5) Support for the continuing avionic system development and enhancement

The design of the rig is such that single equipments, subsystems or the complete aircraft system msy be exercised. This is achieved through a modular construction technique. Each module or bench houses single equipments or a subsystem, the system interfacing wiring and any special simulation necessary for stand alone operation. Apart from actual cable lengths and their individual routing the interfacing wiring is in other respects a reproduction of the aircraft wiring and conforms to aircraft standarda. The wiring is broken via patch panels to provide access to the system data flow and to enable equipment isolation for stand slone test purposes. A photograph of the Tornado F Mk 2 rig is shown in Figure 1.

At all times testing is performed using as much of the actusl aircraft equipment as possible, therefore, the rig is subjected to the same configuration controls as the aircraft. This control extends to the modification state of both the rig wiring and the aircraft equipment in use, including the equipments installation on and removal off the rig.

The rig life cycle extends for many years from the initial project development phase testing, through to aircraft in service support and beyond. The original Jaguar rig is approaching 15 years of continued use and is still actively employed on weapon system enhancement support work.

4. THE TORNADO F MK 2 RIG

Although the design of this rig follows the same basic philosophy as that for the Jaguar and Tornado IDS counterparts it deviates in the fact that it is capable of simulated flight. During flight, navigation tasks can be performed and the full extent of the weapon aiming system facilities can be exercised.

To achieve this capability a number of additional features from other development areas have been incorproated into the rig design. These features, some of which originate from flight simulation and mathematicsl modelling techniques, are described in the following sections. A schematic diagram of the rig facility is shown in Figure 2.

Cockpits

To accommodate the crew for the rig 'aircraft', detailed mock-ups of both pilot and navigators cockpits are provided. Both cockpits are designed to accept the installation of the relevant aircraft equipments. The pilots cockpit is also equipped with operational aircraft controls such as stick, throttle and airbrakes. The electrical outputs from these controls are fed as inputs to the rig DASS.

DASS

The rig DASS which comprises of two PDP 11/55 computers represents a major advance over its Tornado IDS predecessor. Although the DASS operates as one machine, functionally it is split into two parts.

Part 1 represents the major interface with the rig and the aircraft system and is responsible for system control, the data logging functions and simulation definitions etc.

Part 2 houses the bulk of the simulation system which can be divided into three major blocks.

(1) The aircraft aerodynamic model

(2) The navigation sensor simulation

(3) The multi target model

The operation of this simulation is best deacribed by considering its performance during the execution of navigation and weapon aiming tasks separately.

Navigation

To convince the avionics system that it is flying, it needs to be presented with representative navigation sensor data. This data is dependent on the aerodynamic state of the aircraft which is realised by the aircraft aerodynamic model. After initialisation this model is driven by variations to the lift, engine and drag characteristics derived from the stick, throttle and airbrake controls in the pilots cockpit. The aerodynamic models output furnishes the necessary stimulus to drive the navigation sensor simulation. This block of simulation provides the source of navigation data for the rest of the aircrafts avionics system. The data is available to all navigation system interfacing equipments and it conforms to the Tornado standards ie it is identical in form and content to that which would be output by the real system for the same flight conditions. Representative navigation sensor data errors can also be included for system accuracy tests as required.

The avionics system, therefore, can be flown and the navigation facilities of the flight software dynamically exercised via the associated cockpit displays and controls.

Weapon Aiming

In addition to being able to perform all the navigation functions, execution of the weapon aiming tasks also necessitates the presence of active target data. This requirement is met by the third block in the simulation system the multi-target model. This model is responsible for the generation and presentation of target data to the aircrafts prime weapon aiming sensor, the multi mode nose radar system.

The targets themselves can be pre-programmed to fly fixed trajectories or respond to a time history manoeuvre list. The total number presented is variable and if necessary any one of the targets can be overridden and controlled separately, from manual inputs, such that evasive manoeuvres can be executed. At all times the model is aware of the rig aircrafts positional data and its radar antenna scan angles. Thus the model calculates when to pass target data to the radar on a strictly "in beam" decision process. In real terms the radar system itself is responsible for much of the target data processing before it is exported to the receiving avionic system equipments. Therefore as much of the radar system as possible has to be kept within the test loop. This means that the target data output by the target model, which is in digital form, has to be converted to an equivalent RF signal before being injected into the radar system.

Radar Target Generator

The process of converting the target data from the model to a radar acceptable RF signal is performed by the Radar Target Generator. This equipment is provided by the radar system manufacturer and is external to the DASS facility. It receives the digital target data from the target model, converts it to an RF equivalent waveform and injects it into the radar system immediately behind the radar antenna on the receiving path.

IFF Target Generator

In a similar fashion the target model also incorporates the ability to satisfy the requirements of the aircrafts IFF interrogator system and targets can be pre-programmed to be friendly or hostile and will be detected as such. As with the radar system the IFF data has to be presented at RF and therefore an IFF Target Generator is also required which is provided by the IFF equipment manufacturer.

The complete target generation system enables representative target data to be presented to the avionics system. Targets are detected, engaged and the weapon aiming and missile management systems exercised up to and including the point of missile releases. This is a very cost effective means of weapon aiming and weapon system development since complex flight trials involving multi target engagements are not required. Testing takes place within the confines of the laboratory with all its advantages of test control and repeatability.

Radar Simulation

In order to support a continued flight test programme it is necessary that the aircraft take highest priority on equipment allocation. There are occasions, therefore, when the rig has to release equipment to the aircraft. In addition it is not always cost effective to dedicate a fully operational radar system to rig work alone. Since rig work on weapon system development is dependent on a source of target data it was thought wise to have available an alternative source other than a complete radar system. This has been achieved, to great effect, by utilising a real radar data processing unit in combination with radar system simulation. In retaining the real radar data processor both the radar system interface with the rest of the avionics and the radar system software are preserved. The target data output by the model interfaces directly with the radar simulation, the RF target generator unit is not required.

Therefore with or without the aircraft radar equipment on the rig, weapon aiming system development can continue uninterrupted.

Simulation Validation

As described previously the avionics rig is subject to the same configuration controls as the aircraft. This control extends to the facilities used on the rig including the system simulations. These simulations which are used to clear aircraft equipment are therefore validated before use through established quality assurance procedures.

5. DYNAMIC MODES OF OPERATION

The process of 'flying' the rig is executed either manually or automatically, depending on the nature of the test requirements. In the automatic modes the rig aircrafts flight profile is derived from either the system modelling process or from aircraft flight trials data.

Manual Operation

This is the main mode of operation which covers the bulk of system development testing. The simulation system is initialised with rig and target aircraft data. The crew then fly the rig aircraft via the pilots cockpit controls and operate the avionics system for the particular test in progress. Data logging, which will have been pre-defined, can be controlled to record the relevant phase or phases of the flight as the test progresses. The trajectories of the rig aircraft and the targets can also be recorded to provide a source of data with which to drive the avionics system model. This enables the test to be rerun on the model which simplifies and reduces the cost of the analysis process since a direct comparison between the rig and model outputs is possible.

For the majority of the time the rig 'aircraft' crew is made up from the test engineers themselves. They are able to fly the avionics system and operate the data acquisition/simulation processes as necessary. Thus if a system abnormality occurs in flight the rig aircraft can be frozen whilst investigation of current data values takes place.

The manual mode of operation is also of great value to actual aircrew. They are able to familiarise themselves with system operation by rehearsing the planned trials before flying the real aircraft. Post flight comments can also be illustrated on the real equipment by aircrew demonstrations to development engineers.

Automatic Operation 1

Certain system development tests demand specific aircraft/target scenarios to be executed. These scenarios are usually the result of extensive system modelling work which has preceeded rig testing, therefore, the avionic system response has already been predicted. From this modelling process a rig forcing tape is produced that contains the necessary driving signals to fly both the rig aircraft and the targets. Thus the pilots flying task is removed and the rig aircraft flys a predetermined fixed profile automatically.

The forcing tape is run on the rig DASS and the flight data is passed directly to the navigation sensor simulation thus bypassing the aircraft aerodynamic model. All system initialisation data is contained on the tape including that for the target aircraft. Although the rig aircraft and the targets respond directly to the data on the forcing tape, the avionics system itself can be operated as required. Therefore the same scenario can be flown repeatedly but with a different weapon aiming mode in operation for each flight. The crew have complete freedom of avionic system operation in this respect it is just the aircraft flight profile that is pre-determined. Far more target engagement scenarios and attack profile combinations can be evaluated in this way than could ever be achieved by using the real aircraft.

As with the case for manual operation data analysis mainly involves matching rig recorded data with system modelling data to identify disparities between the two. Inequalities of this nature are then subjected to further in depth analysis or additional rig tests.

Rig forcing in this manner is the means by which the system performance, predicted by the model, is compared to that of the actual aircraft avionics equipments. Close interaction therefore exists between these two facilities leading to a more accurate and representative system model as well as avionic system validation.

There is a further mode of automatic operation which differs in one respect only and that is in the source of the forcing data.

Automatic Operation 2

The second mode of automatic operation brings in yet another element of the development facilities ie the aircraft.

Suitable recording of aircraft data during actual flight testing trials represents an additional source of forcing data for both the system model and the rig. The in-flight data has to be re-formatted to produce the necessary forcing tape for rig use but the data values remain as per aircraft. Thus it is possible to re-run a flight trial on the rig should flight back up testing be necessary. The actual aircrew can be used to operate the rig avionics system as they did during the flight trial. Therefore in-flight problems can be closely examined on the rig under representative operational conditions without the need for extra flight trials.

Once again a close interaction exists between the aircraft, the rig and the system model and further mutual refinement of these facilities is achieveable.

6. ADVANTAGES OF THE DYNAMIC TESTING APPROACH

The major advantage of adopting the dynamic testing approach on the avionics development rig is one of cost reduction, rig 'flying' time costs are far less than those for the aircraft. Reductions in the flight test programme devoted to avionics development have occurred and a more efective use of flight testing time is being achieved. These points are all illustrated by the following factors :

(1) The operational clearance of the avionics system to the aircraft is of a higher standard and is more precisely defined. Criticisms of the system operation by the aircrew now concentrate on moding and design philosophy as opposed to operational malfunctions

(2) A greater appreciation of the actual system operational capabilities is available at an earlier stage in the development programme. This leads to improved forward planning of the flight test programme to maximise the data gathering process.

(3) Problems that do arise in flight, that would have previously required extra flying time in the pursuit of the solution, can now be addressed on the rig. We have at our disposal a much improved flight test back up facility.

(4) Pre-flight, system operational demonstration to aircrew on the rig is more extensive and meaningful. Thus, incidents during flight due to 'finger trouble' or system operation unfamiliarity are reduced.

(5) Post flight comments by aircrew on system operation particularly those on cockpit displays can be easily illustrated with reference to demonstration on the rig. This leads to a better understanding and interpretation of the comments by the development engineers.

Additional advantages are also apparent that do not directly affect the flight test programme but are still worth mentioning :

The engineers working on the rig enjoy dynamic testing and the ability to 'fly' the system.

Their interest and appreciation of the whole system is increased as is their commitment to the development task. This is accompanied by improved reporting and problem area identification.

An improved standard of aircraft groundcrew training is being achieved by utilising the dynamic capabilities of the rig.

The use of the rig as a demonstrator of the system operational facilities to potential customers has been greatly enhanced.

7. FUTURE DEVELOPMENTS

The main trend of future developments will undoubtedly have as their objective a further reduction in system development costs. This will be achieved by accommodating more of the avionics content of the flight test programme on the rig. Hence, this programme will be reduced to a series of system operational confirmation and validation flights. It will also be the aim to reduce the rig testing timescales to speed up the system clearance to the aircraft. One aspect that will contribute significantly to this aim is the automation of the data reduction and analysis process. The rig and the system model could be run in parallel at the same time from the same forcing data. The two sets of results would be continually compared and the error signals output as the end product. Signal disparities would therefore be available at the end of the test run.

To assist in future systems design the rigs themselves can be linked so that one rig aircraft system is flown against another. Using the Tornado IDS rig as a target aircraft for the Tornado F Mk 2 system has already been discussed. Through this development, combat situations would be executed on the rigs using the full avionics systems of both aircraft plus additional simulations. Further studies of system effectiveness, optimum system usage and crew workloads could be accommodated.

One aspect of system operation that will soon be studied with little or no modification to the existing facilities is that of reversionary modes. It is a fairly simple matter to intentionally cause avionic equipment failures during flight on the rig. The consequences of single and multiple equipment failures can thus be examined without putting the aircraft at risk.

8. CONCLUSIONS

This paper has introduced the philosophy adopted at British Aerospace Warton for the pre-flight ground testing of avionics systems.

Particular reference has been made to the Tornado F Mk 2 avionics development rig and its ability to simulate flight through the use of dynamic testing techniques. These techniques, involving an integrated approach to the use of the development facilities available and a growth in the use of computing, have had a significant effect on reducing the overall system development costs due to :

(1) A reduction in the flying hours devoted to avionic system developments

(2) More effective use of the flight testing time available.

The success of this approach has been such that both the Tornado IDS and Jaguar rigs, which preceeded the Tornado F Mk 2 rig, have now been uprated to facilitate dynamic testing. The impact on these projects has been the same as that experienced on the Tornado F Mk 2 project.

Fig.1 THE TORNADO F Mk 2 AVIONICS DEVELOPMENT RIG.

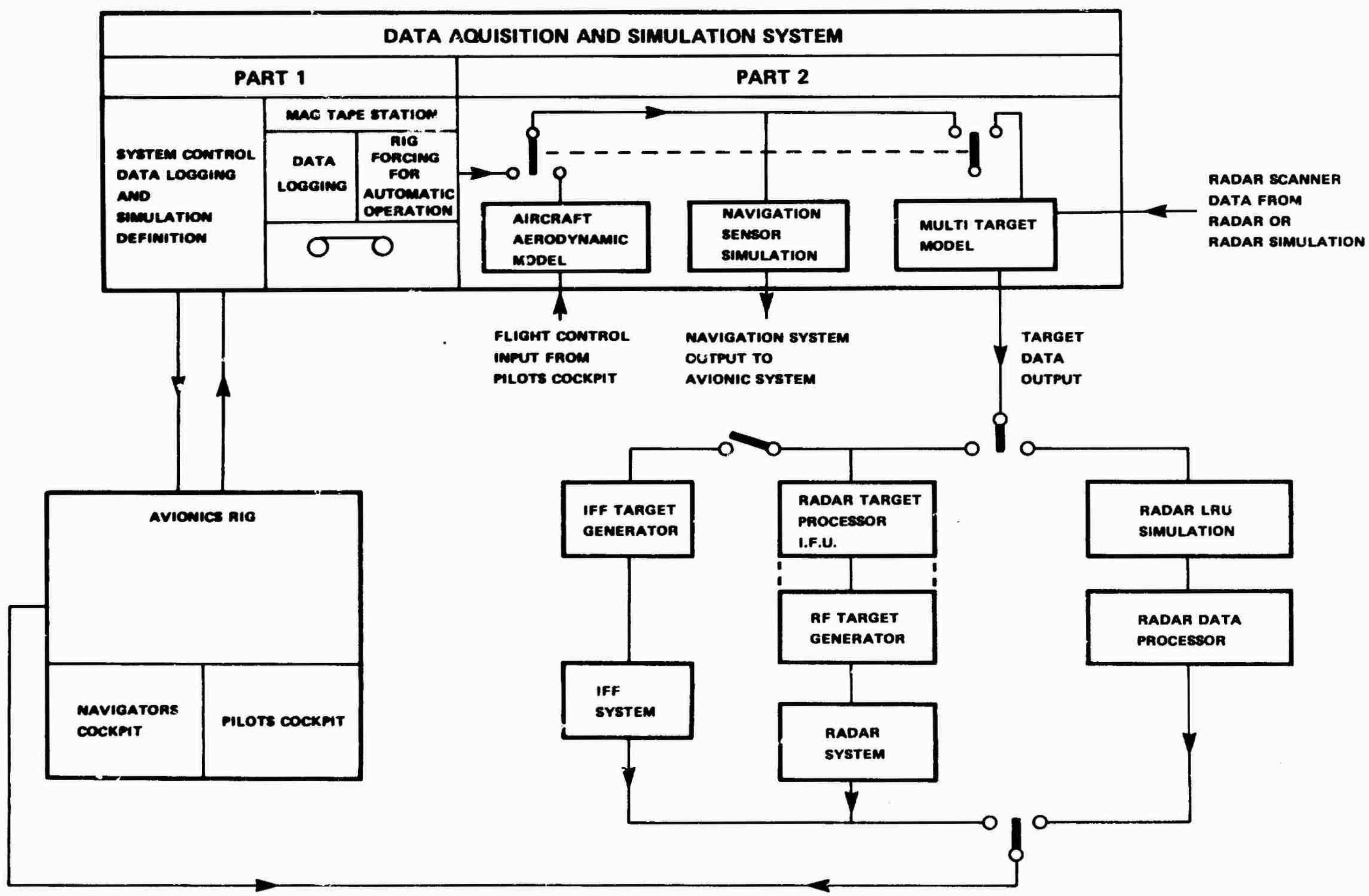

Fig.2 SCHEMATIC DIAGRAM OF TORNADO F Mk 2 AVIONICS DEVELOPMENT RIG.

DISCUSSION

K.F.Boecking, Ge

Do you use the rig as an aid for avionics development only or do you use it for simulation also (e.g. aircraft handling qualities or attack-profiles etc.)?

Author's Reply

Aircraft handling testing is conducted on our Flight Controls Rig which is a separate facility to the one described in the paper. The flight Control Rig is used to test and verify the Autopilot & Flight Director and command stability augmentation systems. Attack profiles, however, are conducted on the Avionic Development Rig as well as Avionics Systems Development.

J.O.Vaillancourt, Ca

(1) How many rigs do you manufacture and are they available for sale to the aircraft purchaser?

(2) Do you have different types of rigs for different aircraft versions?

Author's Reply

We have built Avionics Systems Development Rigs, similar to that described in the paper, for Jaguar, Jaguar fly-by-wire and Tornado IDS aircraft. In addition a Flight Controls Rig for the Tornado IDS/ADV aircraft also exists. The Avionics Rigs are to accommodate future system developments for a particular aircraft or aircraft type. We have indeed built such avionic rigs for the customer. I.e. the RAF have a Jaguar rig and a Tornado IDS rig. These rigs are built to meet the specific requirements of the customer and are manufactured by the same team that produce our own rigs.

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Modern aircraft weapon systems are being structured with more interdependency among subsystems. In order to realize the benefits of advanced integration while achieving the required performance, new design and development concepts were presented. Sessions were devoted to System Design Criteria, Avionics and Systems State-of-the-Art, System Development Concepts, and System Integration and Test.

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